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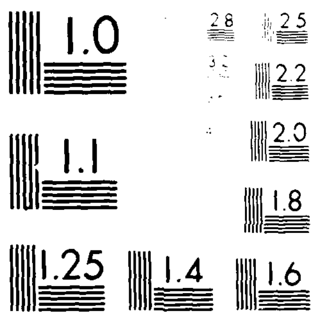

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Systems Research &
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Economic Analysis of Airport Pavement Rehabilitation Alternatives

An Engineering Manual

J. A. Epps
C. V. Wootan

October 1981

Final Report

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16. Abstract

The manual describes a method for evaluation of pavement rehabilitation alternatives based on a present worth or present value economic model. Methods for selecting pavement rehabilitation, recycling and maintenance alternatives are presented together with a method for determining thickness requirements for overlay on airport pavement facilities.

Guidelines are presented to allow the engineer to select an appropriate discount rate, analysis period and salvage values for use in the life cycle cost calculations. Prices and costs of pavement rehabilitation and recycling maintenance techniques are given and are suggested for use if costs of these operations are not available from historical records. Cost updating procedures are also defined.

Two example problems are included in the manual to illustrate the techniques of present worth life cycle costing.

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Unclassified	Unclassified	82	

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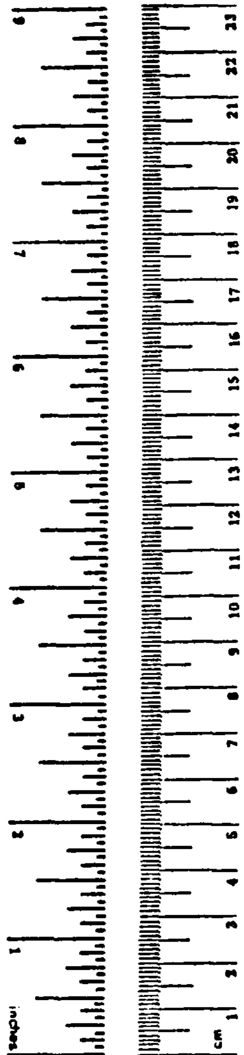
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

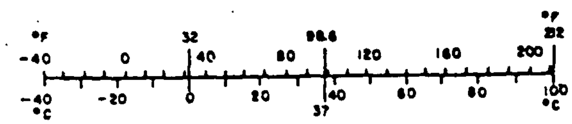
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

The engineer responsible for the rehabilitation and maintenance of the pavements on an airport is responsible for allocating his monetary resources in an optimum manner. Thus, he must decide what portion of the facility he intends to include in his rehabilitation program as well as what specific rehabilitation action is most appropriate for a particular section of the pavement.

A number of pavement management techniques have been developed in the last 10 years to assist the engineer in making these maintenance and rehabilitation decisions (1-13). These techniques have for the most part been developed for highway pavements (5, 6, 8, 9, 10, 11, 12, 13); however, more recent efforts have addressed the problems associated with airport pavements (1, 2, 3, 4, 7). The methodology developed by these researchers for the most part is dependent upon the use of computer programs.

The purpose of this manual is to provide the working engineer with a simplified economic tool for evaluating a wide variety of airport pavement rehabilitation and maintenance strategies including a number of pavement recycling alternatives. The engineer is, however, encouraged to use the more advanced computer oriented approach developed at the Construction Engineering Research Laboratory (1, 2, 3, 4) for airport pavements where practicable.

The manual contains an economic technique suitable for selection of a rehabilitation or maintenance strategy for a particular project. The technique suggested makes use of the principles of engineering economy and methods of economic evaluation. Thus, cost information is required together with information defining the life of various rehabilitation and maintenance alternatives. Rehabilitation and maintenance cost information is projected for the life of the project and techniques are utilized to reduce these costs at various ages to a common economic base. Hence, the term "life cycle analysis" is utilized to describe the techniques. Costs are reduced to their present worth which is often referred to as present value.

PAVEMENT RECYCLING

In the last six years the reuse or recycling of existing pavement materials has emerged as a viable rehabilitation and maintenance alternative. Surface recycling projects have been performed at airports and airfields located in the following cities: China Lake, California (14); El Paso, Texas (15); Hobbs, New Mexico (14); Long Beach, California (16); Los Angeles, California (14, 17); Mountain Home, Idaho (14); Pampa, Texas (14); Point Mugu, California (14); San Francisco, California (14); and Travis, California (14). Cold recycling has been performed at two airports in Massachusetts [Orange (18) and Martha's Vineyard (19)] and at Cut Bank Montana (20). Hot recycling techniques were utilized in Las Vegas and in Minnesota (21). The major benefits cited for recycling on these projects are lower costs; conservation of aggregates, binders and energy; preservation of the environment; and preservation of the existing pavement geometrics.

Since the benefits of recycling appear promising from a wide variety of viewpoints, a number of agencies including the National Cooperative Highway Research Program (NCHRP) have sponsored research (22, 23). NCHRP Synthesis 54, "Recycling Materials for Highways" was the first comprehensive summary of recycling information (22). Federal Highway Administration sponsored programs include: Demonstration Project No. 39, "Recycling Asphalt Pavement" (24, 25); Demonstration Project 47, "Recycling Portland Cement Concrete Pavement" (26); National Experimental and Evaluation Program (NEEP) Project No. 22 (27); Implementation Package 75-5 (28); Office of Research studies on "Softening or Rejuvenating Agents for Recycled Bituminous Binders", "Tests for Efficiency of Mixing Recycling Asphalt Pavements", "Data Bank for Recycled Bituminous Concrete Pavement" and "Materials Characterization of Recycled Bituminous Paving Mixtures" and special state studies including those conducted with Highway Planning and Research funds (29, 30). Other government studies have been performed by the Air Force (31) and the Navy (32) under joint sponsorship with the Federal Aviation Administration.

Associations and Institutes that have contributed to the collection and distribution of recycling information include the American Concrete Paving Association, Asphalt Emulsion Manufacturers Association, Asphalt Recycling and Reclaiming Association, The Asphalt Institute (33), National Asphalt Pavement Association (34, 35), Portland Cement Association (36) and West Coast User-Producer Group on Asphalt Specifications (37). In addition conference sessions and symposiums have been held on pavement recycling at the Transportation Research Board, American Society for Testing and Materials (38) and Association of Asphalt Paving Technologists meetings.

Definitions

The term pavement recycling has not been formally defined. However, most individuals concerned with roadway rehabilitation use the term to indicate "the reuse (usually after some processing) of a material that has already served its first-intended purpose in a roadway" (39).

Definitions for recycling categories have been prepared by the Federal Highway Administration Demonstration Project No. 39, Technical Advisory Committee (25), a joint National Asphalt Pavement Association-Asphalt Institute Committee (40), Asphalt Recycling and Reclaiming Association (41), National Cooperative Highway Research Program (22, 23), U. S. Air Force Civil Engineering Center (31) and Naval Civil Engineering Laboratory (32). Although formal definitions for recycling categories have not been developed, those advanced by a joint National Asphalt Pavement Association, The Asphalt Institute and Federal Highway Administration committees are the most widely accepted and are given below:

Asphalt-Pavement Surface Recycling. One of several methods where the surface of an existing asphalt pavement is planed, milled, or heated in-place. In the latter case, the pavement may be scarified, remixed, relaid and rolled. Additionally, asphalt softening agents, minimal amounts of new asphalt hot-mix, aggregates, or combinations of these may be added to obtain desirable mixture and surface characteristics. The finished product may be used as the final surface or may, in some instances, be overlayed with an asphalt surface course.

Cold-Mix Asphalt Pavement Recycling. One of several methods where the entire existing pavement structure including, in some cases, the underlying untreated base material, is processed in-place or removed and processed at a central plant. The materials are mixed cold and can be reused as an aggregate base, or asphalt and/or other materials can be added during mixing to provide a higher strength base. This process requires that an asphalt surface course or surface seal coat be used.

Hot-Mix Asphalt Pavement Recycling. One of several methods where the major portion of the existing pavement structure including, in some cases, the underlying untreated base material, is removed, sized, and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate and/or a softening agent. The finished product is a hot-mix asphalt base, binder, or surface course.

Portland Cement Concrete Pavement Recycling. A process by which an existing portland cement concrete pavement is processed into aggregate and sand sizes, then used in place of, or in some instances with additions of conventional aggregates and sand, into a new mix and placed as a new portland cement concrete pavement. This process is a phase of the econocrete concept in that the broken concrete is considered to be a local aggregate.

The selection of recycling (as described above) over other pavement rehabilitation and maintenance alternatives for a given airport must be based on economics. Methods for selecting rehabilitation alternatives for a given pavement section are discussed below.

SELECTION OF REHABILITATION ALTERNATIVES

The selection of a rehabilitation alternative for a given pavement section is dependent upon a number of factors including the following (Figure 1):

1. Type, extent and degree of pavement distress on existing pavement
2. Roughness of existing pavement
3. Load carrying ability of existing pavement
4. Skid resistance of existing pavement
5. Location and size of project
6. Type of facility (runway, taxiway, parking apron, etc.)
7. Existing pavement cross section including thicknesses and type of materials
8. Geometrics including vertical alignment and cross slopes
9. Traffic characteristics including volume and type of aircraft
10. Subgrade characteristics

All of these factors must be considered in the selection process.

Detailed discussions describing the selection process can be found in References 1, 2, 3, 4, 23 and 42. References 1-4 describe the technique developed for airfields by the Construction Engineering Research Laboratory. This method is computerized and is the most comprehensive document available to guide the engineer in selecting a rehabilitation alternative. Unfortunately, few recycling techniques have been included as possible rehabilitation alternatives.

Reference 23 describes a process that can be utilized to select recycling rehabilitation and maintenance alternatives. This procedure was developed for highway pavements; however, the framework presented in the report can be utilized to select appropriate recycling options for airport pavements.

Reference 42 was also developed for highway pavements. A methodology is described which allows the selection of either conventional or recycling pavement rehabilitation alternatives. The selection method is based on the pavement condition in terms of the type and degree of distress.

Since the purpose of this manual is to describe the economic tools available to the engineer upon which an engineering decision can be made, additional detail concerning selection of rehabilitation alternatives will not be presented. The engineer should, however, be aware of the basic differences between airport and highway pavements if rehabilitation alternatives are to be selected based on information developed for highway pavements. These basic differences are associated with (1) the magnitude of the wheel loads, (2) the number of repetitions and (3) the thicknesses of the pavement layers.

OVERLAY THICKNESS DETERMINATIONS

Selection of a rehabilitation or maintenance alternative is largely dependent upon the thickness of overlay required. If a thick overlay is required several rehabilitation alternatives cannot be utilized unless they are used in combination with a thick overlay. Examples of some of these unsuitable alternatives are chip seals made with either asphalt cement or asphalt-rubber binders, heater-scarification and slurry seal.

The Federal Aviation Administration Advisory Circular 150/5320-6C, "Airport Pavement Design and Evaluation" is recommended for determining the thickness of overlay or recycled layers required (43). The Circular describes methods to determine the thickness of the following types of overlays.

1. Bituminous overlays on existing flexible pavements
2. Bituminous overlays on existing rigid pavements
3. Unbonded concrete overlays on rigid pavements
4. Bonded concrete overlays on rigid pavements

The basic steps involved in the overlay design method are as follows:

1. Determination of foundation conditions under existing pavement
2. Determination of the actual thickness of each layer
3. Determination of the condition and strength of existing pavement layers
4. Determination of the pavement thickness required above the subgrade for the type and volume of aircraft expected to use the facility
5. Determination of the thickness of overlay required over the existing pavement by subtracting the required thickness from the actual thickness or by use of an overlay design formula.

Determination of the overlay thickness therefore requires an evaluation of the condition of the existing materials as well as the load carrying equivalency factors for the new or recycled materials. As a first approximation it can be assumed that the load carrying equivalency factors for recycled materials are identical to conventional materials where the same type of binders are utilized (23, 44).

ECONOMIC ANALYSIS METHOD

A review of the literature suggests that the best method for measuring economic worth for pavement rehabilitation alternatives is that of present worth (present value). The present worth of a required rehabilitation and maintenance strategy can be viewed as the amount of money that must be available at the present time in order to have sufficient funds to pay for not only the immediate rehabilitation that is required but also the anticipated future rehabilitation and maintenance operations needed through some selected period in the future.

In order that the present worth of rehabilitation and maintenance can be determined, several key items of information need to be determined and/or established. These factors include a definition of costs, selection of a discount rate, selection of an analysis life, development of a methodology for determination of salvage value and establishment of the life of various rehabilitation alternatives. These factors are considered below.

Costs Associated With Pavement Rehabilitation

The initial and recurring costs that an agency may consider in the economic evaluation of alternative rehabilitation strategies have been defined in Reference 45 and include the following:

1. Agency costs
   a. Initial capital costs of rehabilitation
   b. Future capital costs of reconstruction or rehabilitation (overlays, seal coats, etc.)
   c. Maintenance costs, recurring throughout the design period
   d. Salvage return or residual value at the end of the design period
   e. Engineering and administration costs
2. User costs
   a. Travel time
   b. Vehicle operation
   c. Accidents
   d. Discomfort
   e. Time delay and extra vehicle operating costs during resurfacing or major maintenance
3. Nonuser costs

Certainly all of these costs should be included if a detailed economic analysis is desired. However, definition of many of these costs is difficult while other costs do not significantly affect the analysis of alternatives for a given pavement segment. For the sake of simplicity the method of analysis usually only considers the following costs:

1. Initial capital costs of rehabilitation
2. Future capital costs of reconstruction or rehabilitation
3. Maintenance costs

4. Salvage value.

It is suggested, however, that certain user costs such as time delay costs during rehabilitation be considered on certain facilities. Factors that must be considered when determining these costs include (7, 46):

1. Will the runway, taxiway, apron, etc. be closed over a lengthy period of time?
2. Are alternate runways, taxiways, etc. available?
3. Can operations be moved to a different facility?
4. What are the costs of traffic delays (aircraft and personnel) associated with closing the facility?

Discount Rate

The discount rate selected must be based on an analytical method which is consistent in its use of either constant dollars (costs stated at price levels prevailing at a particular date in time) or current dollars (costs stated at price levels prevailing at the time the costs are incurred). A discount rate based on the market rate of return is consistent with the use of current dollars in estimating future costs. One using the real rate of return is consistent with the use of constant dollars.

The practice of using constant dollars for economic analysis together with market rate of return (current interest rate) for discounting future costs to present values is a rather common practice. However, this methodology is in error and should not be used since the market rate of return includes: (1) an allowance for expected future inflation as well as (2) a return that represents the real cost of capital. (In private investment decisions there is also included an allowance for risk; however, in Federal investments this is considered to be negligible and generally ignored.) The use of constant dollars for costing future rehabilitation and maintenance alternatives, on the other hand, makes no provision for anticipated inflation. Thus, if future costs and salvage values are calculated in constant dollars, only the real cost of capital should be represented in the discount rate used (47, 48).

Constant Dollar Studies. As stated above, when constant dollar costs are used for future pavement rehabilitation and maintenance costs, the real cost of capital should be used in the analysis. The real cost of capital may be thought of as an inflation free rate of return on assets. Market interest rates approach the real cost of capital when inflation is zero. The real long term rate of return on capital has been between 3.7 and 4.4 percent since 1966 (47, 49). A discount rate of return of four percent is therefore suggested for present value calculations in this manual when constant dollars are used to estimate future rehabilitation and maintenance costs and salvage value.

Current Dollar Studies. If costs are projected in inflated or current dollars, the full market rate of interest should be used. A range of eight to twelve percent has been commonly used to represent the average long-term market interest rate in recent economic studies of public projects. The United States Office of Management and Budget prescribes a ten percent discount rate for most federal government economic studies using current dollar costs (49).

If current dollar costs are employed in the study, use of an average rate of inflation for all price changes is recommended unless there are good reasons to expect highly significant differences in the rate of price change for certain rehabilitation and/or maintenance alternatives (50). Table 1 indicates average annual rates of inflation for a number of construction cost indices as well as construction, rehabilitation and maintenance materials. Inflation rates for construction and rehabilitation and maintenance materials are in general higher than those experienced for consumer commodities as expressed by the Consumer Price Index.

Discussion. Except for special cases where some items are expected to have significantly different rates of inflation, the consensus of economists is to use constant dollar costs and discount rates which represent the real cost of capital. In general, economists outside of government agree on this approach and cite the following primary reasons against inclusion of inflation rates in economic studies:

1. Difficulties in predicting future inflation rates
2. The acceptance of inflation as a norm may be counter to the Government's duty for price stabilization
3. Federal programs, if justified in part by inflating benefits, may themselves contribute to inflation
4. Debtors' gains through repaying outstanding debts with inflated dollars are offset by creditors' losses
5. Future dollars to pay for future expenses will likewise be inflated and therefore there is no net change
6. A bias toward capital-intensive and long-lived projects results, making adaption to future changes more costly than otherwise (50).

Recommendation. Comparison of pavement rehabilitation alternatives should be based on the use of constant dollars for estimating present and future costs together with salvage values. A discount rate of four percent is suggested for present value calculations associated with the use of this manual.

Because the results of present value are sensitive to the discount rate, the analyst may want to perform the economic calculations at two or three alternative discount rates. It should be noted that rehabilitation alternatives with large initial costs and low maintenance or user costs are favored by low interest rates. Conversely, high interest rates favor strategies that combine low initial costs with high maintenance and user costs.

A discount rate of four percent has been utilized for examples in this manual. Present worth factors and capital recovery factors for discount rates of 3.5, 4.0, 4.5 and 5.0 percent are shown in Table 2. Values for other discount rates can be found in Reference 51 or textbooks on engineering economy. Both present worth and the uniform annual cost methods are illustrated in the manual. Costs are estimated in terms of dollars per square yard.

Analysis Life

In economic studies, projects under consideration are defined as having a service life, an economic life and an analysis life. Service life estimates the actual total usage of a facility. It is the time span from installation of a facility to retirement from service. The ending of service life of a pavement (except by disaster) is by man-made decision.

The economic life is the life in which a project is economically profitable or until the service provided by the project can be provided by another facility at lower costs. The economic life may be less than the service life. Shortage of capital often extends a project service life beyond the end of its economic life.

Analysis life may not be the same as the service life or economic life of a project, but it represents a realistic estimate to be used in economic analysis. The analysis period utilized should be long enough to include the time between major rehabilitation actions for the various rehabilitation activities under study. However, the analysis period should not be excessive as the analysis becomes more uncertain due to changes in technology and/or events not occurring as predicted. The Highway Engineering Handbook (52) "stresses that use of an analysis life not to exceed 40 years on the basis that a sound investment should return its costs within that length of time".

An analysis period of 20 years is suggested for use when evaluating pavement rehabilitation alternatives unless the life of a selected alternative is expected to exceed 20 years. An analysis period of 20 years has been utilized for examples in this manual.

Salvage Value

Salvage value is the economic residual value of the facility at the end of the analysis period for the project. The present value of this residual value is used to partially offset the present worth of the project costs. In a broad sense, the salvage value is the remaining value of the land, equipment and facility of the project that has continued or alternative uses at the end, or terminal year of the analysis period.

In several studies made on salvage value of pavements it was considered valid to assume zero salvage value at the end of the analysis period (53, 54). However, the evaluation of pavement rehabilitation alternatives requires that some consideration be given to salvage value (4, 12). The residual value of rehabilitation action based on its anticipated remaining life appears to be the best method for determining salvage value in this manual. A simplified but adequate method is described by the equation given below:

$$SV = \left(1 - \frac{L_A}{L_E}\right) C$$

where

SV = salvage value or residual value of rehabilitation alternative

L_A = analysis life of the rehabilitation alternative in years i.e., difference between the year of construction and the year associated with the termination of the life cycle analysis

L_E = expected life of the rehabilitation alternative.

C = cost or price of rehabilitation alternative

For example, if an analysis period of 20 years is utilized on a project where a rehabilitation alternative has a life cycle of seven years, the residual or salvage value of the second rehabilitation action is equal to the straight-line depreciated value of the alternative at the end of the analysis period as given by the equation above. Thus, the residual value at the 20th year would be

$$SV = (1 - \frac{6}{7})\ 2.50 = \$0.36$$

if the cost of the rehabilitation alternative was $2.50.

Life of Rehabilitation Alternatives

The expected life of rehabilitation alternatives must be based on the engineer's experience with consideration given to local materials, environmental factors and contractor capability. For example, overlay design lives of 20 years are utilized for thickness design calculations. In practice the life is usually of the order of 12 to 15 years.

PRICE DATA

Data are included in this manual which define prices associated with pavement construction, reconstruction, recycling and maintenance operations. These prices are intended to be representative only and are updated prices for the year 1980 based on data given in References 23 and 55. If prices for these operations are available from local agencies' historical records or local contractors, they should be substituted appropriately because a large price variation can be expected depending on the location of the project and the time of construction.

The engineer should be aware that the term "pavement price" refers to the total amount of monies that an agency, or the public, must spend to have a pavement structure constructed, rehabilitated or maintained. Pavement price includes pavement cost, general contractor overhead and contractor profit. Pavement cost is defined as the amount of monies that a contractor must spend for labor, materials, equipment, subcontracts and overhead to construct, rehabilitate or maintain a pavement structure.

Construction Prices

Prices of common pavement construction operations are shown in Table 3. These prices are considered representative of average in-place prices in the United States. Prices are based on pavement layers in the range of 4 to 8 inches for untreated base and stabilized layers. Asphalt concrete prices are typical of 1.5 to 3 inch lifts while portland cement concrete prices are typical for pavements 8 to 10 inches in thickness. These thicknesses are typical of those found on general aviation airports and highway pavements.

Rehabilitation and Pavement Recycling Prices

Prices associated with selected rehabilitation and pavement recycling operation prices are shown in Tables 4, 5 and 6. The common rehabilitation activities of asphalt concrete overlays, chip seal costs, etc. can be found in Table 4. Recycling prices are shown in Tables 5 and 6.

Maintenance Costs

Costs associated with flexible pavement maintenance operations are shown in Table 7 and with rigid pavement maintenance operations in Table 8. Costs were obtained from the states of California, Florida, Iowa, Louisiana, Nevada, New Jersey and North Dakota and are representative of costs in 1980.

A general description for each maintenance activity has been prepared and is shown in the tables together with the average, low and high unit costs for these activities. The reported suggested costs are the author's best estimate of representative unit costs for the stated maintenance activity. The wide range of reported unit costs for this condensed list of activities is due in part to:

1. Different crew sizes utilized in the various areas
2. Different equipment requirements for various areas
3. Differences in maintenance work activity as defined by various agencies
4. Variety of traffic conditions under which maintenance is performed
5. Type of facility on which maintenance activities are performed
6. Amount of work performed per square yard or other unit of measurement

Maintenance unit cost information has been converted to costs per square yard of total pavement surface area treated (Table 9). In order to develop these costs, assumptions were made as to the thickness and extent of the area treated. Costs associated with maintenance activities of different thicknesses and extent can be calculated from Tables 7 and 8.

The summary of maintenance information contained in the previous tables is for 11 flexible and 5 rigid highway pavement activities. Costs representative of airport pavement maintenance operations are not available in summary form. As a first approximation, highway maintenance costs can be used to represent airport maintenance costs. If there is a need for determining maintenance costs for activities other than those listed in Tables 7, 8 and 9, it will be necessary to obtain data from local state, county, or city governments or contractors that perform those activities.

Airport Versus Highway Prices

Price data reported in this manual are based primarily on information obtained from highway construction projects. Highway prices and costs are readily available to the engineer in summary form. Price data for airport construction, rehabilitation, recycling and maintenance operations are not available in summary form. Bid tabulation forms from

25 reconstruction and rehabilitation projects have been obtained however, and are summarized in Tables 10 and 11. The variability in prices associated with highway and airport projects is so large when defining national average prices that, in all probability, a statistically significant difference could not be ascertained between prices for these two types of pavements (46).

PRICE UPDATING PROCEDURES

As price information is obtained from various sources at various times, it is necessary to bring these prices to a common time frame. In order to convert price figures contained in this manual to a current date, the price or cost index method is suggested. The following equation can be used.

$$C_c = C_o \left(\frac{I_c}{I_o} \right)$$

where: C_c = Current estimated cost

C_o = Cost at other time "O"

I_c = Current index number

I_o = Index number at other time "O"

The index number to use depends upon the type of cost being estimated. Four indices are commonly available and can be used.

1. The ENR Construction Cost Index (56)
2. Bid Price Trends on Federal-Aid Highway Contracts (57)
3. The ENR Equipment Price Index (56)
4. The Cost Trends on Highway Maintenance and Operations (58)

The ENR Construction Cost Index (Table 12) was designed as a general purpose construction cost index to chart basic costs with time. It is a weighted index of constant quantities of structural steel, portland cement, lumber and common labor, valued at $100 in 1913.

The Bid Price Trends on Federal-Aid Highway Contracts is compiled by the Federal Highway Administration as reported by state transportation agencies (Table 13). The base year for this index is 1967.

The ENR Equipment Price Index is compiled from Bureau of Labor statistics and is published periodically by Engineering News Record (for a base year of 1967).

The Cost Trends for Highway Maintenance and Operations (Table 14) are given through 1979 (the latest year available).

For price and cost data presented in this manual the following 1980 index numbers are suggested:

1. ENR Construction Cost Index (1980), $I_c = 3237$
2. Highway Bid Price Trends on Federal-Aid Highway Contracts (1980), $I_c = 347.9$
3. Cost Trends on Highway Maintenance and Operations (1979), $I_c = 239.79$

Future Price Trends

The information contained in Tables 12-14 can be supplemented and used to project future price trends associated with materials used for construction, rehabilitation and maintenance. Figures 2 and 3 illustrate the rate of increase in costs since 1967 (59). The rapid increases in prices between 1973 and 1974 were a result of ending federal price controls and of the Arab oil embargo. Highway price moderations during the period 1974 to 1977 were a result of a general decrease in highway construction work (more competition for the same projects) and moderation of the general rate of inflation and crude oil prices.

It is important to realize that considerable regional and local price differences exist throughout the United States. Figure 4 illustrates the differences among the prices of asphalt concrete in Texas, Region 6 of the FHWA (Texas, Oklahoma, Ne Mexico, Arkansas and

Louisiana) and the average price for the United States. Similar differences are noted in Figures 5-9 for common excavation, portland cement concrete pavement, reinforcing steel, structural steel and structural concrete (57).

Three primary reasons which are responsible for price increases for pavement construction, rehabilitation, recycling and maintenance activities are the prices of crude oil, asphalt cement and the cost of transportation. Figure 10 illustrates the price of imported crude oil from 1973 to present (60). (The United States presently imports about 45 percent of its crude oil.) Figure 11 shows the price increases associated with asphalt cement in Texas (61). Similar price increases are noted throughout the United States. The present posted price of asphalt cement is about 175 dollars F.O.B. refinery. Transportation cost increases closely follow the price increases associated with crude oil (Figure 12) (62).

A review of the attached cost trends indicates the following annual rates of inflation for the various items during the period 1973-1980 in the United States (see Table 1 for a more complete list).

Item or Index	Annual Rate of Inflation, Percent
Building cost index	8.0
Construction cost index	8.0
Highway bid price index	12.5
Highway maintenance cost index	8.9
Asphalt concrete	14.1
Portland cement concrete	11.5
Excavation	12.5
Mideastern crude oil	45.7
Asphalt cement	25.8
Rail transportation (Figure 11)	13.0

The expected rate of cost increases for many construction related items in the 1980 to 1981 period are expected to be approximately 15-20 percent. The expected price increases associated with consumer goods for the years 1981 to 1990 are shown in Table 15 (63).

ANALYSIS PROCEDURES

Based on the information presented above, present worth or present value economic evaluation methods appear to be the best methods to utilize for evaluating airport pavement rehabilitation and maintenance strategies. A discount rate of four percent is suggested for use in this manual together with an analysis period of 20 years. Salvage values should be calculated based on the residual value equal to the straight-line depreciated value of the rehabilitation alternative at the end of the analysis period. The life and initial price of the various rehabilitation, recycling and maintenance alternatives should be based on the engineer's experience with consideration given to local materials, environmental factors and contractor capability. Typical price and cost data have been included for reference purposes. Cost updating procedures included will allow the engineer to predict prices for planned rehabilitation projects.

The basic equation for determining present worth of rehabilitation and maintenance for a given facility is shown below:

$$PW = C + M_1 \left(\frac{1}{1 + r}\right)^{n_1} + \ldots M_i \left(\frac{1}{1 + r}\right)^{n_i} - S \left(\frac{1}{1 + r}\right)^{z}$$

where:

- PW = Present worth or present value
- C = Present cost of initial rehabilitation activity
- M_i = Cost of the i^{th} maintenance or rehabilitation alternative in terms of present costs, i.e., constant dollars
- r = Discount rate (four percent suggested for use in this manual)
- n_i = Number of years from the present to the i^{th} maintenance or rehabilitation activity

S = Salvage value at the end of the analysis period

z = Length of analysis period in years (20 years suggested for use in this manual)

The term

$$\left(\frac{1}{1 + r}\right)^n$$

is commonly called the single payment present worth factor in most engineering economic textbooks. From a practical standpoint, if the difference in the present worth of costs between two rehabilitation alternatives is 10 percent or less, it is normally assumed to be insignificant and the present worth of the two alternatives can be assumed to be the same (12).

Table 16 is a calculation form for determining the present worth of a rehabilitation alternative. The use of this form is illustrated in an example that follows in the next section of the manual.

Table 17 has been developed to aid the engineer in preparing information for life cycle costing, summarizing the results of the present worth calculation and aiding in the selection of the most promising rehabilitation and maintenance activities. Table 17 contains a section for describing the location of the project, type of facility, design aircraft, annual departures and the existing pavement. These data can be used together with Reference 43 for determining overlay thicknesses. The first cost, life cycle cost, time required for rehabilitation and the chance of successfully rehabilitating the pavement by the use of the rehabilitation strategy are summarized at the bottom of Table 17. Engineering judgement must be utilized to establish the chance of success associated with the various rehabilitation alternatives.

Table 18 is a convenient form for recording prices and costs associated with the various strategies under study. Cost comparisons and life cycles of the various rehabilitation and maintenance alternatives can be readily compared on this table.

Step By Step Procedure

Information presented in this manual can be utilized with the identified references to provide cost comparisons for various rehabilitation and maintenance alternatives on specific airport projects. The following step by step procedure is suggested. Example problems follow.

1. Identify and record on Table 17 key project descriptions such as:
   a. Location
   b. Type of facility
   c. Critical aircraft
   d. Annual departures of aircraft
   e. Existing pavement layers, thicknesses, etc.
2. Determine the condition of the existing pavement and record data such as the following on Table 17.
   a. Condition of pavement (Reference 1)
   b. Skid resistance
   c. CBR of subgrade
3. Determine required thickness of overlay required (Reference 43)
4. Identify feasible rehabilitation and maintenance alternatives (References 3, 23 and 42)
5. Record life cycle cost information on Table 16 for each alternative to be evaluated. Cost information should be obtained from local agencies' historical records, or local contractors or from information supplied in this manual. Engineering judgement based on field performance must be utilized to define the needed maintenance and the life of rehabilitation alternatives.
6. Summarize life cycle present worth costs on Table 17 together with the alternative's first cost, the length of time required for rehabilitation and the chance of the rehabilitation alternative performing as described on life costing sheet (Table 16)
7. Select the most promising rehabilitation alternative based on factors such as life cycle cost, first cost, length of time

required to rehabilitate, maintainability of the selected rehabilitation strategy and user safety during construction.

Use of the proposed procedure is illustrated below:

EXAMPLE PROBLEMS

Two example problems are discussed below which illustrate the use of the present worth life cycle costs techniques described in the manual.

Example 1 - Light Aircraft Facility

A general aviation airport runway located in the southwest is in need of rehabilitation. The existing pavement contains alligator, transverse and longitudinal cracks as described in Table 18. The critical aircraft using the facility has a 24,000 lb. gross weight. A three inch overlay is required to rehabilitate the facility (43), Seven rehabilitation alternatives including surface, in-place and hot central plant recycling are being considered. Life cycle cost information is shown in Table 19 for these alternative strategies. Present worth calculations for alternative number 1 are shown in Table 20. Table 21 gives representative initial costs for each alternative. Maintenance costs are those associated with crack pouring and an occasional digout and repair. The recurring cost of $2.50 is for a 1.5 inch overlay.

Life cycle present worth costs are summarized in Table 18 for each of the seven alternatives. The costs of alternatives 1, 3, 4, 5 and 6 are within ± 10 percent of $7.00 per square yard. Based on the low life cycle cost, reasonable first cost, the relative short period of time required for construction and the high chance of successfully completing the rehabilitation as scheduled, alternative 4 is recommended for this specific example.

The lowest cost alternative may have been a different alternative if different lives and/or maintenance costs had been utilized. The engineer is encouraged to use the life cycle costing technique described above for his or her particular project and to utilize other price assumptions and different expected life considerations to evaluate a spectrum of reasonable assumptions for these two important inputs.

Example 2 - Major Airport

A major airport located in the southeast contains a taxiway that is badly cracked in the central 25 feet. This taxiway is 6,000 feet in length and 100 feet in width. A basic description of this facility is shown in Table 22. An overlay thickness of seven inches would be required over the central portion of the taxiway according to the method described in Reference 43.

The cost of a seven inch overlay over the entire taxiway is $770,000 assuming the cost per square yard-inch is $1.65. Since only the central portion of the taxiway is in need of repair two other alternatives are being considered. The second alternative involves the partial removal of the existing base, removal of surface and replacement with new conventional materials. The third alternative involves partial removal of the base, removal of the surface and replacement with stabilized recycled materials. Both of these alternatives will require a two inch overlay across the entire taxiway. Cost summaries are given below:

Alternative No. 1 - Seven inch overlay of entire taxiway

Cost of overlay @ $1.65 per square yard-inch =	$770,000

Alternative No. 2 - Removal and replace with conventional materials

Remove and waste four inches of asphalt concrete @ $0.50* per square yard-inch =	$40,000
Remove and waste eight inches of untreated base @ $0.40 per square yard-inch =	64,000

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*Includes increased transportation and disposal costs.

Replace with 10 inches of bituminous base course	
@ $1.50 per square yard-inch =	300,000
Replace with two inches of bituminous surface	
course @ $1.65 per square yard-inch =	66,000
Overlay entire taxiway with two inches of	
bituminous surface course	
@ $1.65 per square yard-inch =	220,000
Total cost =	$690,000
<u>Alternative No. 3</u> - Removal and recycle	
Remove and size four inches of asphalt concrete	
@ $0.50 per square yard-inch =	$40,000
Remove eight inches of untreated base	
@ $0.30 per square yard-inch =	48,000
Replace with 12 inches of hot recycled material	
@ $1.15 per square yard-inch =	276,000
Overlay entire taxiway with two inches of	
bituminous surface course	
@ $1.65 per square yard-inch =	220,000
Total cost =	$584,000

If it is assumed that each of these alternatives has equal future maintenance and rehabilitation requirements, it is apparent that the recycling alternative has the lowest first cost as well as life cycle present worth and is therefore suggested for use.

SENSITIVITY ANALYSIS

Present worth life cycle cost determinations are sensitive to the following factors:

1. Selected discount rate
2. Length of analysis period
3. Life of rehabilitation alternative
4. Salvage value

5. Price and cost values

6. Consideration of user costs.

Sensitivity analyses have been conducted for various pavement designs in South Africa (12). Figures 13 and 14 illustrate the influence of discount rate and salvage value on the present worth of typical flexible and rigid pavements. The engineer is encouraged to vary the variables identified above for various rehabilitation strategies investigated for his specific project before making a final selection of an appropriate action.

CONCLUSIONS

This manual has attempted to describe and justify a simplified economic procedure for evaluating a wide variety of airport pavement rehabilitation and maintenance strategies. Included in these strategies are a number of pavement recycling alternatives.

The examples that are shown are intended to guide the engineer through the evaluation process. Cost data, while current, will soon be out of date and should be updated with more current local costs before individual evaluations leading to strategy decisions are undertaken.

References are included with the manual for two purposes. First, to buttress procedural documentation and secondly, to indicate sources of price and cost data for future updating. Again it should be stressed that local conditions may vary from broad averages, and that whenever possible local prices and costs should be used in all alternative analyses.

RECOMMENDATIONS

It is the authors' recommendation that the economic analyses described in this manual form the base for evaluating the alternatives available to the engineer in his airport rehabilitation program. Those alternatives that appear to be technically feasible should have life cycle costs developed in the manner prescribed.

While example costs are developed as guidelines, it should be remembered that they are the most current prices available and they will not long remain current in our rapidly changing economy. In addition, they are generally average costs and may not be representative of local conditions. Consequently the engineer should check local prices, contractor capability and resource availability before developing his economic analysis.

Use of this manual is therefore recommended on a trial basis. Actual project data should be obtained from 15-20 projects which have or will consider recycling as one of several pavement rehabilitation alternatives. Analysis of these results will indicate under what general circumstances recycling is a cost effective rehabilitation alternative, i.e, long haul distances to new aggregate sources, partial replacement of facilities, etc. Input from these trials will also identify those items in the manual that should be revised for clarity. A revised manual should be prepared based on this trial implementation which will define airport recycling costs, define general types of projects where recycling is economically attractive and revised sections of the manual to improve its usefulness to the practicing engineer.

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Table 1. Annual Rates of Inflation for Various Construction and Maintenance Items.

Item or Index	Reference	Annual Rate of Inflation for Years Indicated			
		70-80	73-80	75-80	79-80
FHWA U.S. Composite Price Index	(57)	10.7	12.5	11.2	12.8
FHWA U.S. Common Excavation Index	(57)	10.7	12.5	12.1	13.3
FHWA U.S. Portland Cement Concrete Surfacing Index	(57)	10.5	11.5	11.2	9.1
FHWA U.S. Bituminous Concrete Surfacing Index	(57)	12.1	14.1	10.8	19.2
FHWA U.S. Reinforcing Steel Index	(57)	11.4	12.8	10.1	14.7
FHWA U.S. Structural Steel Index	(57)	10.7	14.1	11.1	24.0
FHWA U.S. Structural Concrete Index	(57)	9.4	10.8	10.2	2.9
FHWA Texas Composite Price Index	(57)	15.6	16.6	15.9	8.1
FHWA Texas Common Excavation Index	(57)	15.3	15.1	17.3	-2.8
FHWA Texas Portland Cement Concrete Surfacing Index	(57)	14.4	15.7	14.1	-4.3
FHWA Texas Bituminous Concrete Surfacing Index	(57)	19.5	19.7	13.0	22.9
FHWA Texas Reinforcing Steel Index	(57)	12.4	13.5	15.9	6.2
FHWA Texas Structural Steel Index	(57)	13.5	15.6	14.4	-0.5
FHWA Texas Structural Concrete Index	(57)	15.0	17.8	20.4	30.3
FHWA Maintenance Total Index	(58)	8.1	8.9	8.6	9.6
FHWA Maintenance Labor Index	(58)	7.9	8.4	8.6	7.0
FHWA Maintenance Material Index	(58)	10.0	12.1	10.1	18.3
FHWA Maintenance Equipment Index	(58)	8.5	10.3	8.8	12.5
FHWA Maintenance Overhead Index	(58)	4.8	4.1	4.0	3.6
ENR Construction Cost Index	(56)	8.9	8.0	7.9	7.8
ENR Building Cost Index	(56)	8.8	8.0	8.2	6.8
U.S. - Paving Asphalt	(62)		25.8	15.6	34.6
U.S. - Portland Cement	(62)		12.3	9.9	9.5
U.S. - Sand, Gravel and Crushed Stone	(62)		9.6	9.4	14.8
U.S. - Imported Mideast Crude Oil	(60)		45.7	21.8	113.3
U.S. - Railroad Freight (Nonmetallic Minerals)	(62)	11.1	13.3	12.6	19.9
U.S. - Railroad Freight (Clay, Concrete, Glass, Stone)	(62)	10.5	12.5	11.4	17.3
U.S. - Consumer Price Index	(59)	7.9	9.2	8.9	13.4

Table 2. Present Worth and Capital Recovery Factors.

	Present Worth Factor				Capital Recovery Factor			
	Interest Rate				Interest Rate			
Years	3.5	4.0	4.5	5.0	3.5	4.0	4.5	5.0
1	0.9662	0.9615	0.9569	0.9524	1.03500	1.04000	1.04500	1.05000
2	0.9335	0.9246	0.9157	0.9070	0.52640	0.53020	0.53400	0.53780
3	0.9019	0.8890	0.8763	0.8638	0.35693	0.36035	0.36377	0.36721
4	0.8714	0.8548	0.8386	0.8227	0.27225	0.27549	0.27874	0.28201
5	0.8420	0.8219	0.8025	0.7835	0.22148	0.22463	0.22779	0.23097
6	0.8135	0.7903	0.7679	0.7462	0.18767	0.19076	0.19388	0.19702
7	0.7860	0.7599	0.7348	0.7107	0.16354	0.16661	0.16970	0.17282
8	0.7594	0.7307	0.7032	0.6768	0.14548	0.14853	0.15161	0.15472
9	0.7337	0.7026	0.6729	0.6446	0.13145	0.13449	0.13757	0.14069
10	0.7089	0.6756	0.6439	0.6139	0.12024	0.12329	0.12638	0.12950
11	0.6849	0.6496	0.6162	0.5847	0.11109	0.11415	0.11725	0.12039
12	0.6618	0.6246	0.5897	0.5568	0.10348	0.10655	0.10967	0.11283
13	0.6394	0.6006	0.5643	0.5303	0.09706	0.10014	0.10328	0.10646
14	0.6178	0.5775	0.5400	0.5051	0.09157	0.09467	0.09782	0.10102
15	0.5969	0.5553	0.5167	0.4810	0.08683	0.08994	0.09311	0.09634
16	0.5767	0.5339	0.4945	0.4581	0.08268	0.08582	0.08902	0.09227
17	0.5572	0.5134	0.4732	0.4363	0.07904	0.08220	0.08542	0.08870
18	0.5384	0.4936	0.4528	0.4155	0.07582	0.07899	0.08224	0.08555
19	0.5202	0.4746	0.4333	0.3957	0.07294	0.07614	0.07941	0.08275
20	0.5026	0.4564	0.4146	0.3769	0.07036	0.07358	0.07688	0.08024
21	0.4856	0.4388	0.3968	0.3589	0.06804	0.07128	0.07460	0.07800
22	0.4692	0.4220	0.3797	0.3418	0.06593	0.06920	0.07255	0.07597
23	0.4533	0.4057	0.3634	0.3256	0.06402	0.06731	0.07068	0.07414
24	0.4380	0.3901	0.3477	0.3101	0.06227	0.06559	0.06899	0.07247
25	0.4231	0.3751	0.3327	0.2953	0.06067	0.06401	0.06744	0.07095
26	0.4088	0.3607	0.3184	0.2812	0.05921	0.06257	0.06602	0.06956
27	0.3950	0.3468	0.3047	0.2678	0.05785	0.06124	0.06472	0.06829
28	0.3817	0.3335	0.2916	0.2551	0.05660	0.06001	0.06352	0.06712
29	0.3687	0.3207	0.2790	0.2429	0.05545	0.05888	0.06241	0.06605
30	0.3563	0.3083	0.2670	0.2314	0.05437	0.05783	0.06139	0.06505

Table 3. Price of Common Pavement Construction Operations - 1980.

Construction Operation	Representative Price Dollars - Per Square Yard - Inch: Average	Range
Crushed Stone Base	0.65	0.35 - 0.85
Gravel Base	0.55	0.25 - 0.85
Lime Stabilized Subgrade	0.35	0.20 - 0.55
Cement Stabilized Subgrade	0.45	0.25 - 0.60
Cement Treated Base	1.10	0.70 - 1.60
Asphalt Treated Base	1.40	0.75 - 1.90
Lime--Fly Ash--Aggregate Base	1.00	0.65 - 1.25
Chip Seal	0.60*	0.40 - 0.90*
Asphalt Concrete	1.65	0.90 - 2.50
Portland Cement Concrete	1.85	1.00 - 2.75

*Price per square yard of surface

$1\ yd^2 = 8.361 \times 10^{-1}\ m^2$

$1\ in. = 2.54 \times 10^{-2}\ m$

Table 4. Price of Pavement Rehabilitation Operations - 1980.

Rehabilitation Operation	Approximate Thickness, Inch	Representative Price Dollars - Per Square Yard	
		Average	Range
Chip Seal Coat	1/2	0.60	0.40 - 0.90
Fabric Interlayers	1/4	1.20	0.75 - 1.75
Asphalt-Rubber Interlayer	1/2	1.25	0.90 - 1.50
Open Graded Friction Course	5/8	1.50	1.00 - 2.50
Asphalt Concrete (Dense Graded)	1	1.65	0.90 - 2.50
Asphalt Concrete (Dense Graded)	2	3.15	1.80 - 4.75
Asphalt Concrete (Dense Graded)	3	4.75	2.60 - 7.00

$1\ yd^2 = 8.361 \times 10^{-1}\ m^2$

$1\ in. = 2.54 \times 10^{-2}\ m$

Table 5. Price of Common Recycling Operations - 1980.

Recycling Operation	Representative Price Dollars - Per Square Yard - Inch*	
	Average	Range
Heat and Plane Pavement - 3/4 inch depth	0.40	0.20 - 0.70
Heat and Scarify Pavement - 3/4 inch depth	0.50	0.20 - 0.90
Cold Mill Pavement	0.85	0.30 - 1.25
Rip, Pulverize and Compact - Existing Pavement less than 5 inches of Asphalt Concrete	0.30	0.20 - 0.50
Rip, Pulverize, Stabilize and Compact - Existing Pavement less than 5 inches of Asphalt Concrete	0.50	0.25 - 0.70
Rip, Pulverize and Compact - Existing Pavement greater than 5 inches of Asphalt Concrete	0.35	0.15 - 0.50
Rip, Pulverize, Stabilize and Compact - Existing Pavement greater than 5 inches of Asphalt Concrete	0.55	0.30 - 1.00
Remove and Crush Portland Cement Concrete	0.70	0.40 1.10
Remove and Crush Asphalt Concrete	0.50	0.25 1.00
Cold Process - Remove, Crush, Place, Compact, Traffic Control - (Cold Process) without Stabilizer	0.55	0.30 - 0.90
Cold Process - Remove, Crush, Mix, Place Compact, Traffic Control - (Cold Process) with Stabilizer	0.65	0.40 1.00
Hot Process - Remove, Crush, Place Compact, Traffic Control - without Stabilizer	0.80	0.50 - 1.40
Hot Process - Remove, Crush, Mix, Place Compact, Traffic Control - with Stabilizer	1.10	0.75 - 1.65

*Costs are for a square yard inch except where listed.

1 yd = 8.361×10^{-1} m^2 1 in. = 2.54×10^{-2} m

Table 6. Representative Price for Asphalt Pavement Recycling Operations - 1980.

Type	Operation	Option or Expected Results		Representative Price Per Square Yard Average	Range	Assumptions
A. Surface	Heater Planer	Without additional aggregate	A1	0.40	0.35 - 0.90	Heat, plane, clean-up, haul, traffic control.
		With additional aggregate	A2	0.55	0.30 - 0.80	Spread aggregate, heat, roll, traffic control and clean-up.
	Heater Scarify	Heater scarify only	A3	0.40	0.25 - 0.90	Heat, scarify, recompact, traffic control (3/4 inch scarification).
		Heater scarify plus thin overlay of asphalt concrete	A4	1.25	0.80 - 1.50	Heat, scarify, recompact, add 50 lbs. of asphalt concrete per square yard, compact, traffic control (3/4 inch scarification).
		Heater scarify plus chip seal or slurry seal	A5	1.00	0.60 - 1.50	Heat, scarify, recompact, place slurry seal or chip seal and traffic control (3/4 inch scarification).
		Heater scarify plus thick overlay	A6	5.00	3.00 - 6.50	Heat, scarify, recompact, add 300 lbs. of asphalt concrete per square yard, compact, traffic control (3/4 inch scarification).
	Surface Milling or Grinding	Surface milling only	A7	0.85	0.30 - 1.50	Milling, cleaning, hauling, traffic control (one inch removal).
		Surface milling plus thin overlay	A8	4.00	2.50 - 5.00	Milling, cleaning, hauling, 200 lbs. of asphalt concrete, traffic control (one inch removal).
		Surface milling plus thick overlay	A9	6.85	4.25 - 8.00	Milling, cleaning, hauling, 400 lbs. of asphalt concrete, traffic control (one inch removal).

(Continued)

Table 6. Continued.

Type	Operation	Option or Expected Results		Representative Price Per Square Yard: Average	Representative Price Per Square Yard: Range	Assumptions
B. In-Place	Asphalt Concrete Surface Less Than 5 Inches	Minor structural improvement without new binder	B1	4.40	2.50 - 6.00	Rip, pulverize and remix to 4 inch depth with 2 inches of asphalt concrete, traffic control.
		Minor structural improvement with new binder	B2	3.65	2.10 - 4.10	Rip, pulverize and remix with stabilizer to 4 inch depth with 1 inch of asphalt concrete, traffic control.
		Major structural improvement	B3	8.10	5.00 - 10.00	Rip, pulverize and remix to 6 inch depth with 4 inches of asphalt concrete, traffic control.
		Major structural improvement with new binder	B4	6.25	4.00 - 8.00	Rip, pulverize and remix with stabilizer to 6 inch depth with 2 inches of asphalt concrete, traffic control.
		Minor structural improvement without new binder	B5	3.50	2.50 - 4.50	Rip, pulverize and remix to 4 inch depth with 2 inches of asphalt concrete, traffic control
		Minor structural improvement with new binder	B6	3.80	2.50 - 4.75	Rip, pulverize and remix with stabilizer to 4 inch depth with 1 inch of asphalt concrete, traffic control.
		Major structural improvement without new binder	B7	6.25	5.00 - 7.50	Rip, pulverize and remix to 6 inch depth with 4 inches of asphalt concrete, traffic control.
		Major structural improvement with new binder	B8	6.40	5.00 - 7.50	Rip, pulverize and remix with stabilizer to 6 inch depth with 2 inches of asphalt concrete, traffic control.

(Continued)

Table 6. Continued.

Type	Operation	Option or Expected Results		Representative Price Per Square Yard: Average	Representative Price Per Square Yard: Range	Assumptions
C. Central Plant	Cold Mix Process	Minor structural improvement without new binder	C1	4.60	4.00 - 5.25	Remove, crush and replace to 4 inch depth with 2 inches of asphalt concrete, traffic control.
		Minor structural improvement with new binder	C2	3.90	2.75 - 5.00	Remove, crush, mix and replace to 4 inch depth with 1 inch of asphalt concrete, traffic control.
		Major structural improvement without new binder	C3	8.00	6.00 - 10.00	Remove, crush and replace to 6 inch depth with 4 inches of asphalt concrete, traffic control.
		Major structural improvement with new binder	C4	6.50	5.00 - 8.00	Remove, crush, mix and replace to 6 inch depth with 2 inches of asphalt concrete, traffic control.
	Hot Mix Process	Minor structural improvement without new binder	C5	6.25	5.00 - 8.00	Remove, crush and replace to 4 inch depth with 1.5 inches of asphalt concrete, traffic control.
		Minor structural improvement with new binder	C6	6.20	5.00 - 8.00	Remove, crush, mix and replace to 4 inch depth with 1/2 inch of asphalt concrete, traffic control.
		Major structural improvement without new binder	C7	8.75	7.00 - 10.00	Remove, crush and replace to 6 inch depth with 3 inches of asphalt concrete, traffic control.
		Major structural improvement with new binder	C8	10.00	8.00 - 12.00	Remove, crush, mix and replace to 6 inch depth with 1 inch of asphalt concrete.

Table 7. Unit Costs for Flexible Pavement Maintenance Operations - 1980.

Descriptive Title	General Description	State	Activity No.*	Reported Average Unit Cost, Dollars	Suggested Cost, Dollars: Average	Low	High	Unit Measured	Adjusted Average Unit Cost, Dollars
Fog Seal - Full Width	Light application of diluted emulsion or a proprietary material over a full lane width in a continuous section.	CAL	01-983	126.35/ton					0.063/yd^2
		NEV	101.06	0.08/yd^2	0.12	0.06	0.21	yd^2	0.08/yd^2
		MD	435	0.21/yd^2					0.21/yd^2
Chip Seal - Partial Width	Application of asphalt and cover aggregate to a limited area.	CAL	01-050	36.15/ton					0.45/yd^2
		CAL	01-051	46.41/ton					0.57/yd^2
		CAL	01-052	48.93/ton					0.61/yd^2
		CAL	01-053	47.73/ton	0.47	0.24	1.91	yd^2	0.59/yd^2
		CAL	01-083	153.98/ton					1.91/yd^2
		LA	411	48.88/yd^2					0.41/yd^2
		NEV	101.04	0.24/yd^2					0.24/yd^2
		MD	412	0.42/yd^2					0.42/yd^2
Chip Seal - Full Width	Application of asphalt and cover aggregate to a full lane width in a continuous section.	CAL	01-054	45.74/ton					0.57/yd^2
		IWA	614	0.45/yd^2					0.45/yd^2
		LA	415	3179/mile	0.40	0.23	0.57	yd^2	0.23/yd^2
		NEV	101.09	0.31/yd^2					0.31/yd^2
		MD	422	0.44/yd^2					0.44/yd^2
Surface Patch Hand Method Pothole Type	Application of a Premix to fill small depressions.	CAL	01-131	142.59/ton					269.50/yd^3
		FLA	411	181.67/ton	250.00	144.00	343.00	yd^3	343.35/yd^3
		LA	412	76.33/ton					144.25/yd^3
Surface Patch - [illegible] Method	Application of a Premix material to the surface of the pavement by hand method.	FLA	413	65.39/ton					123.60/yd^3
		LA	417	47.86/ton	150.00	90.45	295.60	yd^3	90.45/yd^3
		LA	414	54.71/ton					103.40/yd^3
		NEV	101.02	156.39/yd^3					295.60/yd^3
Surface Patch - Machine Method	Application of a Premix material to the surface of the pavement with machine.	CAL	01-021	49.16/ton					92.90/yd^3
		CAL	01-022	34.97/ton					66.10/yd^3
		CAL	01-023	23.41/ton					44.25/yd^3
		CAL	01-024	30.20/ton					57.10/yd^3
		CAL	01-025	29.16/ton					55.10/yd^3
		FLA	412	60.48/ton	60.00	30.27	114.30	yd^3	114.30/yd^3
		IA	611	20/05/ton					37.90/yd^3
		LA	416	32.82/ton					62.00/yd^3
		NEV	101.03	30.27/yd^3					30.27/yd^3
		NJ	071	25.25/ton					47.70/yd^3
		MD	421	35.28/yd^3					35.28/yd^3
Digout and Repair - Hand Method	Removal and repair of limited areas by use of hand tools.	CAL	01-034	130.75/ton					238.30/yd^3
		FLA	414	60.11/ton	160.00	109.55	238.30	yd^3	109.50/yd^3
		MD	411	127.52/yd^3					127.52/yd^3

(Continued)

Table 7. Continued.

Descriptive Title	General Description	State	Activity No.*	Reported Average Unit Cost, Dollars	Suggested Cost, Dollars: Average	Low	High	Unit Measured	Adjusted Average Unit Cost, Dollars
Digout and Repair - Machine Method	Removal and repair of limited areas by use of mechanized equipment.	CAL	01-111	44.94/ton					81.90/yd^3
		CAL	01-012	40.81/ton					74.40/yd^3
		FLA	414	60.11/ton					109.55/yd^3
		LA	413	31.41/yd^3	90.00	26.11	151.05	yd^3	31.41/yd^3
		NEV	101.01	26.11/yd^3					26.11/yd^3
		NJ	066	77.41/ton					141.10/yd^3
		NJ	067	82.89/ton					151.05/yd^3
Crack Pouring	Pouring cracks in flexible pavement with asphalt material (may include cleaning with compressed air and covering with sand	CAL	01-041	6.71/gal					6.71/gal
		CAL	01-042	10.03/gal	6.25	2.37	10.03	gal	10.03/gal
		NEV	101.07	0.73/lb					6.10/gal
		NJ	068	314.91/ln mi					6.00/gal
		MO	414	2.37/gal					2.37/gal
Slurry Seal	Sealing the roadway with a mixture of emulsion, cement and aggregate and placed by machine	IA	617	0.24/yd^3	0.25			yd^2	0.24/yd^2
Heater Planing	Heating and planing the surface to remove bumps, ripples, wheel ruts, etc.	IA	619	0.90/yd^2					0.90/yd^2
		LA	418	34.60 each	0.70	0.28	0.90	yd^2	0.85/yd^2
		NEV	111.08	0.28/yd^2					0.28/yd^2

*A number which defines the maintenance operation and used in the states' maintenance management system.

Table 8. Unit Costs for Rigid Pavement Maintenance Operations - 1980.

Descriptive Title	General Description	State	Activity No.*	Reported Average Unit Cost, Dollars	Suggested Cost, Dollars: Average	Low	High	Unit Measured	Adjusted Average Unit Cost, Dollars
Mudjacking	Drilling holes and pumping concrete slurry under slab to fill the voids and raise the slab to grade.	CAL	02-011	370.50/yd^2					370.50/yd^2
		FLA	421	255.13/Slab	6.00	4.00	370.50	yd^2	8.70/yd^2
		FLA	422	144/ft^2					-
		IA	621	82.23/yd^3					
		NJ	074	117.73/Slab					4.00/yd^2
Temporary Patching	Patch with bituminous material	CAL	02-021	172.26/ton					325.55/yd^3
		CAL	02-022	38.23/ton	180.00	72.25	325.55	yd^3	72.25/yd^3
		IA	609	126.77/ton					239.60/yd^3
		IA	610	78.72/ton					148.80/yd^3
		NEV	111.01	123.44/yd^3					123.45/yd^3
Permanent Patching	Patch with P.C.C.	IA	613	33.54/yd^2					123.15/yd^3
		NEV	111.02	402.24/yd^3	270.00	134.15	402.24	yd^3	402.24/yd^3
Joint Sealing	Cleaning joint, pour joint and apply sand as required.	CAL	02-042	7.91/gal					7.91/gal
		CAL	02-043	6.50/gal					6.50/gal
		FLA	423	318.00/mile	7.50	3.06	12.40	gal	-
		IA	612	3.06/gal					3.06/gal
		NEV	111.05	1.49/lb					12.40/gal
		NJ	070	167.61/unit					
Expansion Joint Repair	Cut along distresses area, clean out area, place filler material.	NEV	111.06	23.91/lin ft	24.00			lin ft	23.91/lin ft

*A number which defines the maintenance operation and used in the states' maintenance management system.

Table 9. Representative Costs for Flexible Pavement Maintenance and Rehabilitation Activities - 1980.

Maintenance Activity	Cost Dollars* Per		Cost Dollars Per Square Yard of Maintenance Performed	Total Pavement Area Treated
	Square Yard	Lane Mile		
Fog Seal - Partial Width	0.09	640	0.18	50 percent
Fog Seal Full Width	0.12	845	0.12	100 percent
Chip Seal - Partial Width	0.07	500	0.47	15 percent
Chip Seal - Full Width	0.40	2,820	0.40	100 percent
Surface Patch - Hand Method Pothole Type	0.14	1,000	13.90	100 percent 2 inch thick
Surface Patch - Hand Method	0.10	730	4.20	2.5 percent 1 inch thick
Surface Patch - Machine Method	0.17	1,170	1.70	10 percent 1 inch thick
Digout and Repair - Hand Method	0.36	2,500	17.80	2 percent 4 miles thick
Digout and Repair - Machine Method	0.75	5,280	15.00	5 percent 6 inch thick
Crack Pouring	0.23	1,630	-	250 lin ft per station

*Costs are for square yards of total pavement surface maintained. For example surface patching by the hand method may have been applied over only 5 percent of total pavement surface area, yet costs reported are for the total pavement.

Table 10. 1980 Bid Prices on FAA Projects.

Item	Description	Location *	Unit	Quantity	Unit Price, $
P-151	Removal of AC Pavement	West-O	yd^2	111,940	0.50
	Removal of PCC Pavement	West-O	yd^2	46,060	1.90
	Removal of Pavements	West-O	yd^2	24,100	0.35
	Removal of AC Pavement	West-M	yd^2	19,300	1.00
	Removal of AC Pavement	West-S	yd^2	4 300	4.60
	Demolition of PCC Pavement	South-D	yd^2	14,500	3.00
	Demolition of AC Pavement	South-D	yd^2	16,500	1.00
	Removal of PCC Pavement	South-J	yd^2	24,000	7.50
	Removal of Existing Pavement	East-W	yd^2	2,236	4.00
	Removal of 8"Non-Reinforced PCC	West-D	yd^2	7,526	5.00
	Removal of PCC Pavement	West-P	yd^2	4,681	5.40
	Removal of AC Pavement	West-P	yd^2	954	2.00
	Removal of Pavement	West-PO	yd^2	3,860	4.75
P-152	Unclassified Excavation	West-O	yd^3	565,000	1.80
	Unclassified Excavation	South-T	yd^3	77,500	2.05
	Pavement and Base Removal - 3" and 8"	South-P	yd^2	250	8.00
P-154	Subbase Course	West-O	yd^3	8,000	3.30
	Work Platform - 8" Limerock	South-D	yd^2	125,340	1.72
P-155	Lime Treated Subgrade - 6"	West-G	yd^2	35,400	2.47
	Lime Treated Subgrade - 6"	West-D	yd^2	8,063	2.72
	Lime Treated Subgrade - 18"	West-D	yd^2	4,484	5.70
P-150	Pavement Milling 0-1.5"	South-M	yd^2	4,200	3.00
	Pavement Milling 0-1.5"	South-M	yd^2	800	14.00
	Pavement Milling 0-1.5"	South-SA	yd^2	13,542	2.50
	Pavement Milling	West-N	yd^3	6,443	17.00
	Pavement Pulverization	West-O	yd^2	48,000	0.80
	Pavement Pulverization	West-OA	yd^2	51,000	1.25

Item	Description	Location*	Unit	Quantity	Unit Price, $
P-201	Bituminous Base Course - Aggregate	South-M	Ton	1,512	38.43
	Bituminous Base Course - Sand	South-M	Ton	235	38.44
	Bituminous Base Course - Aggregate	South-M	Ton	10,205	47.08
	Bituminous Base Course - Sand	South-M	Ton	1,290	50.33
	Bituminous Base Course	South-P	Ton	13,735	29.16
	Bituminous Base Course	West-W	Ton	250	30.45
P-209	Crushed Aggregate Base	West-O	yd^3	49,200	11.00
	Aggregate Base	West-M	Ton	9,000	8.00
	Aggregate Base	West-F	Ton	1,065	11.00
	Aggregate Base	South-D	yd^3	3,500	11.00
	Aggregate Base	West-G	yd^3	5,900	1[illegible].70
	Crushed Limestone Aggregate	West-R	yd^3	5,000	20.00
	Crushed Rock Base	West-P	Ton	3,696	9.00
	Aggregate Base	West-OA	Ton	4,300	7.40
	Crushed Aggregate Base	West-PO	yd^3	3,630	16.20
P-211	Lime Rock Base Course	South-T	yd^3	27,500	32.00
	Lime Rock Base Course - 18"	South-D	yd^2	81.158	6.44
	Lime Rock Base Course - 12"	South-D	yd^2	33,800	4.00
	Lime Rock Base Course - 6"	South-D	yd^2	18,860	3.00
	Lime Rock Base Course - 18"	South-M	yd^2	110,730	6.50
	Lime Rock Base Course - 12"	South-M	yd^2	21,460	3.75
	Lime Rock Base Course - 6"	South-M	yd^2	19,560	3.00
	Lime Rock Work Platform - 3"	South-M	yd^2	132,370	2.00
	Lime Rock Base Course - 18"	South-M	yd^2	34,250	7.50
	Lime Rock Base Course - 6"	South-M	yd^2	15,010	3.20
	Lime Rock Work Platform - 3"	South-M	yd^2	23,310	2.80
	Lime Rock Base Course - 8"	South-R	yd^2	31,250	5.65
P-212	Shell Base Course	South-T	yd^3	687,500	25.00

Item	Description	Location*	Unit	Quantity	Unit Price, $
P-213	Sand/Clay Base Course - 6"	South-P	yd^2	12,750	1.90
	Soil Cement Base	West-O	yd^3	52,600	16.10
P-301	Soil Cement Base - 4"	South-A	yd^2	11,450	2.15
	Soil Cement Base - 6"	South-A	yd^2	11,450	2.99
	Econocrete Base Course	South-J	yd^2	26,375	11.27
P-304	Recycled Econocrete Course	South-J	yd^2	26,375	11.65
	Cement Treated Base Course - 8"	West-W	yd^2	18,265	11.67
	Asphalt Concrete Surface	West-O	Ton	44,410	22.93
	Asphalt Concrete Surface	West-M	Ton	2,350	28.00
	Asphalt Concrete Surface	West-F	Ton	4,720	29.00
	Asphalt Concrete Surface	West-S	Ton	106,400	34.31
	Asphalt Concrete Surface	South-T	Ton	39,400	33.60
	Asphalt Concrete Surface	South-D	Ton	13,800	32.46
	Asphalt Concrete Surface	South-M	Ton	21,153	41.00
	Asphalt Concrete Surface	South-M	Ton	14,260	50.29
	Asphalt Concrete Surface	South-R	Ton	1,731	34.26
	Asphalt Concrete Surface	South-P	Ton	6,160	29.16
	Asphalt Concrete Surface	South-C	Ton	3,035	26.75
	Asphalt Concrete Surface	South-SM	Ton	7,180	28.20
P-401	Asphalt Concrete Surface	South-S	Ton	1,150	29.37
	Asphalt Concrete Surface	South-RD	Ton	4,700	27.50
	Asphalt Concrete Surface	South-SA	Ton	41,500	27.25
	Asphalt Concrete Surface - 2"	South-A	yd^2	11,450	4.20
	Asphalt Concrete Surface Course	East-W	Ton	2,622	37.00
	Asphalt Concrete Surface - Type B	West-W	Ton	65	30.45
	Asphalt Concrete Surface	West-P	yd^2	3,222	5.00
	Asphalt Concrete - Class B	West-O	Ton	20,500	25.00
	Asphalt Concrete Surface	West-OA	Ton	7,750	28.45
	Asphalt Concrete Surface - Class B	West PO	Ton	10,950	32.70
	Asphalt Concrete Surface - Class D	West PO	Ton	1,900	35.60
	Recycled Asphalt Concrete	West-N	Ton	12,927	25.55

Item	Description	Location*	Unit	Quantity	Unit Price, $
	PCC Pavement	West-O	yd^3	97,310	56.82
	PCC Pavement - 14"	South-D	yd^2	33,800	25.20
	PCC Pavement - 14"	South-M	yd^2	17,380	37.00
	PCC Pavement - 16"	South-J	yd^2	26,375	30.00
	PCC Pavement - 10"	South-J	yd^2	520	22.00
P-501	PCC Pavement - 6"	South-A	yd^2	11,450	12.43
	PCC Pavement - 16" Non-Reinforced	West-W	yd^2	16,383	32.30
	PCC Pavement - 16" Reinforced	West-W	yd^2	1,018	35.45
	PCC Pavement - 9" Reinforced	West-D	yd^2	8,031	33.00
	PCC Pavement - 14" Reinforced	West-D	yd^2	5,269	47.00
	PCC Pavement - 19" Reinforced	West-D	yd^2	4,651	54.00
	PCC Pavement	West-P	ft^2	42,125	5.50
	Bituminous Prime Coat	West-O	Ton	374	190.00
	Bituminous Prime Coat	West-M	Ton	19	300.00
	Bituminous Prime Coat	West-S	Ton	315	265.00
	Bituminous Tack Coat	West-S	Ton	344	220.00
	Bituminous Prime Coat	South-T	gal	53,000	1.40
	Bituminous Tack Coat	South-T	gal	7,500	2.30
	Bituminous Prime Coat	South-D	gal	15,000	2.00
	Bituminous Tack Coat	South-D	gal	8,000	1.00
	Bituminous Prime Coat	South-M	gal	22,800	3.15
P-602	Bituminous Tack Coat	South-M	gal	13,325	1.05
	Bituminous Prime Coat	South-M	gal	7,400	3.47
	Bituminous Tack Coat	South-M	gal	6,980	1.16
	Bituminous Prime Coat	South-R	gal	6,250	1.30
	Bituminous Tack Coat	South-R	gal	3,100	1.15
	Bituminous Prime Coat	South-P	gal	5,100	1.08
	Bituminous Tack Coat	South-P	gal	7,185	0.75
	Bituminous Tack Coat	South-C	gal	3,680	0.85
	Bituminous Tack Coat	South-SM	gal	8,700	0.88
	Bituminous Prime Coat	South-RD	gal	5,200	1.00
	Bituminous Tack Coat	South-RD	gal	1,050	1.00

Item	Description	Location*	Unit	Quantity	Unit Price, $
	Bituminous Tack Coat	South-SA	gal	22,000	1.22
	Bituminous Prime Coat	South-A	gal	5,700	1.33
	Bituminous Tack Coat	West-N	gal	18,409	1.60
P-602	Bituminous Prime Coat	West-G	gal	9,000	0.94
	Bituminous Prime Coat	West-W	gal	3,655	1.15
	Bituminous Tack Coat	West-W	gal	125	1.15
	Bituminous Tack Coat	West-O	gal	15,000	0.70
	Bituminous Prime Coat	West-OA	Ton	75	2.82
	Bituminous Tack Coat	West-OA	Ton	2	3.10
	Chip Seal	West-S	yd^2	20,400	3.95
	Chip Seal	South-D	yd^2	825,000	0.90
	Chip Seal	South-M	yd^2	100,000	1.42
P-609	Chip Seal	South-SM	yd^2	3,940	0.85
	Chip Seal	South-S	yd^2	40,000	1.42
	Chip Seal	West-N	yd^2	46,000	1.18
	Slurry Seal	West-S	yd^2	309,600	1.05
	Slurry Seal	West-O	yd^2	2,200	2.00
	Fabric	South-S	yd^2	32,040	1.43
P-640	Fabric	South-P	yd^2	670	2.25
	Fabric	South-SA	yd^2	83,500	1.00

*Codes used to designate specific airports.

Table 11. Summary of Selected 1980 FAA Bid Prices.*

Item	Description	Unit	Price, Dollars Low	High	Representative	No. of Projects
P-150	Pavement Milling 0-1.5"	yd^2	2.50	14.00	3.00	3
	Pavement Pulverization	yd^2	0.80	1.25	1.00	1
P-151	Removal of AC Pavement	yd^2	0.50	4.60	2.00	5
	Removal of PCC Pavement	yd^2	1.90	7.50	4.00	4
	Removal of Pavement	yd^2	0.35	4.75	2.00	3
P-154	Subbase Course	yd^2-in	0.10	0.57		2
P-155	Lime Treated Subgrade	yd^2-in	0.32	0.45	0.40	3
P-201	Bituminous Base Course	yd^2-in	1.53	2.47	2.05	6
P-209	Aggregate Base Course	yd^2-in	0.31	0.56	0.42	9
P-211	Lime Rock Base Course	yd^2-in	0.31	0.93	0.55	12
P-212	Shell Base Course	yd^2-in			0.70	1
P-213	Sand/Clay Base Course	yd^2-in			0.32	1
P-301	Soil Cement Base	yd^2-in	0.45	0.53	0.50	3
P-304	Cement Treated Base	yd^2-in			1.45	[illegible]
P-401	Asphalt Concrete Surface	yd^2-in	1.20	2.64	1.70	22
	Recycled Asphalt Concrete	yd^2-in			1.35	1

(continued)

Table 11. Continued.

Item	Description	Unit	Price, Dollars Low	High	Representative	No. of Projects
P-501	PCC Pavement - Non-Reinforced	yd^2-in	1.58	2.64	2.00	7
	PCC Pavement - Reinforced	yd^2-in	2.22	3.67	3.00	4
P-602	Bituminous Prime Coat	yd^2	0.16	0.69	0.22	13
	Bituminous Tack Coat	yd^2	0.04	0.14	0.06	13
P-609	Chip Seal	yd^2	0.85	3.95	1.10	6
	Slurry Seal	yd^2	1.05	2.00	1.25	2
P-640	Fabric Interlayers	yd^2	1.00	2.25	1.50	3

*Based on Table 10.

Table 12. ENR Construction Cost Index History 1960-1981.*

	Monthly												Annual Average
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
1960	812	813	813	815	823	827	829	830	831	830	830	831	824
1961	834	834	834	838	847	850	854	854	854	854	855	855	847
1962	855	858	861	863	872	873	877	881	881	880	880	880	872
1963	883	833	884	885	894	899	909	914	914	916	914	915	901
1964	918	920	922	926	930	935	945	948	947	948	948	948	936
1965	948	957	958	957	958	969	977	984	986	986	986	988	971
1966	988	997	998	1006	1014	1029	1031	1033	1034	1032	1033	1034	1019
1967	1039	1041	1043	1044	1059	1068	1078	1089	1092	1096	1097	1098	1070
1968	1107	1114	1117	1124	1142	1154	1158	1171	1186	1190	1191	1201	1155
1969	1216	1229	1238	1249	1258	1270	1283	1292	1285	1299	1305	1305	1269
1970	1309	1311	1314	1329	1351	1375	1414	1418	1421	1434	1445	1445	1385
1971	1465	1467	1496	1513	1551	1589	1618	1629	1654	1657	1665	1672	1581
1972	1686	1691	1697	1707	1735	1761	1772	1777	1786	1794	1808	1816	1753
1973	1838	1850	1859	1874	1880	1896	1901	1902	1929	1933	1935	1938	1895
1974	1940	1940	1940	1961	1961	1993	2040	2076	2089	2100	2094	2101	2020
1975	2103	2128	2128	2135	2164	2205	2248	2274	2275	2293	2292	2297	2212
1976	2305	2314	2322	2327	2357	2410	2414	2445	2465	2478	2486	2490	2401
1977	2494	2505	2513	2514	2515	2541	2579	2611	2644	2675	2659	2669	2577
1978	2672	2681	2693	2698	2733	2753	2821	2829	2851	2851	2861	2869	2776
1979	2872	2877	2886	2886	2889	2984	3052	3071	3120	3122	3131	3140	3003
1980	3132	3134	3159	3143	3139	3198	3260	3304	3319	3327	3357	3376	3237
1981	3372	3373	3394										

How ENR builds the Index: 200 hours of common labor at the 20-cities average rate, plus 25 cwt of standard structural steel shapes at the mill price, plus 22.56 cwt (1.128 tons) of portland cement at the 20-cities average price, plus 1,088 board feet of 2 x 4 lumber at the 20-cities average price.

*1913 Base Year

(After Reference 56)

Table 13. Bid Price Trends on Federal Aid Highway Contracts.

			Surfacing			Structures					
	Excavation Price (y^3)	Index*	PCC Price (y^2)	Bit. Conc. Price (t)	Combined Index	Rein. Steel Price (lb)	Struc. Steel Price (lb)	Struc. Conc. Price (y^3)	Combined Index	Highway Bid Price Index	ENR Building Cost Index**
1967	0.54	100.0	4.43	6.47	100.0	0.131	0.247	70.30	100.0	100.0	100.0
1970	0.66	121.8	5.42	8.04	123.3	0.163	0.338	92.73	132.2	125.6	124.4
1971	0.67	123.8	6.06	8.54	134.5	0.177	0.348	92.02	138.5	131.7	141.1
1972	0.72	133.4	6.25	9.22	141.9	0.181	0.342	100.17	140.6	138.2	156.0
1973 Av.	.80	147.1	6.87	9.99	154.8	0.207	0.373	111.83	156.5	152.4	169.3
Q1	0.67	124.7	6.57	9.85	150.3	0.181	0.295	109.34	141.9	137.8	
Q2	.75	138.0	6.36	9.90	148.2	0.193	0.352	113.51	153.4	145.9	
Q3	.81	149.5	7.10	9.61	154.7	0.212	0.422	110.60	162.1	155.1	
Q4	.93	172.7	7.43	10.83	167.7	0.233	0.379	113.51	162.0	167.8	
1974 Av.	1.00	184.1	8.67	14.74	211.3	0.340	0.551	136.80	214.5	201.8	191.2
Q1	.97	179.1	8.17	13.28	194.6	0.281	0.459	129.64	190.2	187.4	
Q2	.96	178.0	8.48	15.77	216.8	0.342	0.555	137.07	215.4	201.4	
Q3	1.02	187.9	8.82	14.64	212.4	0.371	0.577	152.57	233.7	209.7	
Q4	1.03	190.6	9.10	15.18	219.7	0.362	0.648	130.33	224.1	209.9	
1975 Av.	1.03	190.6	8.62	15.13	213.8	0.297	0.554	138.76	210.5	203.8	194.3
Q1	1.02	188.1	9.84	13.95	219.1	0.332	0.577	140.93	219.7	207.3	
Q2	1.00	184.9	8.22	14.35	203.2	0.320	0.542	139.85	213.1	199.3	
Q3	1.02	188.8	8.49	15.58	215.5	0.283	0.556	142.13	211.5	203.9	
Q4	1.10	202.6	9.00	16.41	227.7	0.277	0.548	131.90	207.9	209.8	
1976 Av.	1.03	191.2	8.65	15.07	213.7	0.257	0.493	138.75	[illegible]	200.4	212.1
Q1	1.04	192.0	7.70	16.28	212.3	0.251	0.543	133.72	[illegible]	200.3	
Q2	1.05	194.3	8.56	14.13	205.5	0.242	0.510	145.65	[illegible]	200.4	
Q3	1.03	191.1	9.18	15.12	219.4	0.264	0.438	135.28	189.6	199.0	
Q4	1.01	187.3	9.17	14.76	217.4	0.271	0.481	141.34	200.4	200.4	

Table 13. Continued.

			Surface			Structures					
	Excavation Price (y^3)	Index*	PCC Price (y^2)	Bit. Conc. Price (t)	Combined Index	Rein. Steel Price (lb)	Struc. Steel Price (lb)	Struc. Conc. Price (y^3)	Combined Index	Highway Bid Price Index	ENR Building Cost Index**
1977 Av.	1.16	215.2	9.68	15.47	228.4	0.272	0.520	143.51	206.8	216.4	229.9
Q1	1.03	189.3	8.69	14.88	212.6	0.262	0.562	139.60	207.6	202.2	
Q2	1.16	214.6	9.41	15.29	224.1	0.268	0.499	149.54	208.3	215.4	
Q3	1.19	219.5	10.05	15.32	231.8	0.273	0.462	139.42	196.9	215.9	
Q4	1.29	237.7	10.32	16.94	247.1	0.285	0.536	148.34	214.1	233.0	
1978 Av.	1.54	233.7	11.49	17.15	262.3	0.315	0.603	172.41	244.4	264.9	249.1
Q1	1.13	209.1	9.68	16.10	233.3	0.283	0.563	151.43	219.4	219.5	
Q2	1.43	263.8	11.96	17.54	270.6	0.310	0.570	171.78	239.5	258.1	
Q3	1.84	339.8	12.04	17.11	268.4	0.346	0.638	198.97	268.9	296.1	
Q4	1.90	350.3	13.06	18.09	237.5	0.334	0.681	176.17	259.0	302.7	
1979 Av.(p)	1.62	298.7	13.47	21.21	315.7	0.421	0.759	220.28	313.1	308.3	270.7
Q1	1.48	278.2	11.59	18.35	272.3	0.381	0.737	195.60	286.6	277.2	
Q2	1.54	284.7	12.91	20.72	305.4	0.411	0.749	202.82	297.5	294.9	
Q3	1.81	334.9	15.09	22.08	341.1	0.429	0.755	215.41	310.1	328.8	
Q4(p)	1.86	343.6	16.85	23.67	373.6	0.489	0.804	240.14	342.6	352.1	
1980 Av.	1.83	338.3	14.69	25.29	360.5	0.483	0.941	226.68	348.0	347.9	289.1
Q1	1.84	339.7	12.34	23.89	322.5	0.472	0.894	234.32	346.7	336.9	
Q2	1.89	350.1	16.29	25.81	383.0	0.515	1.063	206.12	351.4	360.2	
Q3	1.72	317.0	15.78	26.28	380.5	0.475	0.792	250.66	347.2	345.4	
Q4	1.89	349.4	14.75	25.36	361.7	0.467	0.834	234.63	339.1	349.7	
1981 Av.											
Q1	1.73	320.4	15.10	24.75	359.3	0.455	0.847	245.17	240.4	346.2	

*1967 Base Year (After References 56 and 57)

**1967 Base Year

Table 14. Cost Trends - Highway Maintenance and Operations[1].

Year	Labor	Material	Equipment	Overhead	Total
1950	43.58	74.53	57.66	57.07	51.31
1951	47.76	81.07	64.34	62.23	56.41
1952	51.15	81.99	66.86	65.05	59.28
1953	52.00	82.54	68.76	65.73	60.33
1954	54.89	83.49	70.40	66.42	62.55
1955	55.94	82.80	74.24	67.71	64.09
1956	58.70	86.91	74.06	70.55	66.31
1957	63.20	60.86	75.66	78.22	70.28
1958	65.74	92.27	78.91	81.21	72.90
1959	67.82	92.40	83.15	81.88	75.17
1960	71.02	94.68	86.98	84.19	78.35
1961	73.25	95.18	87.19	85.08	79.82
1962	76.06	96.66	88.76	86.47	82.09
1963	79.46	96.87	89.25	88.05	84.32
1964	81.79	97.48	91.25	89.98	86.35
1965	85.69	99.23	94.23	92.31	89.66
1966	98.02	99.68	96.70	96.28	97.76
1967	100.00	100.00	100.00	100.00	100.00
1968	103.63	102.03	100.42	105.03	102.79
1969	113.71	106.24	104.24	110.24	110.44
1970	122.02	111.03	106.56	116.81	116.78
1971	129.67	117.37	107.93	122.76	122.68
1972	138.21	124.27	119.98	128.71	131.68
1973	148.04	130.42	133.70	134.66	141.75
1974	160.67	170.41	153.50	140.61	158.65
1975	173.15	198.74	170.58	145.56	172.97
1976	192.99	192.74	184.37	152.51	188.08
1977	211.89	202.66	194.17	158.51	202.92
1978	226.70	233.41	208.63	164.41	218.80
1979	242.63	276.14	234.64	170.37	239.79

[1] These data are prepared for the unit cost information submitted each year by State highway departments, and cover both physical maintenance and major traffic service items including snow and ice control.

1967 = Base Year (After Reference 58)

Table 15. Predicted Inflation Rates 1981-1990.

Economic Indicator	Average Annual Rates of Change, Percent
Consumer Price Index	9.0
Fuel	15.0
International Commodity Prices (non-fuel)	13.0
Average Hourly Wages	10.0
Farm Prices	8.0
Transportation Equipment	7.5
Furniture, Household Durable Goods	7.0

(After Reference 63)

Table 16. Calculation Form for Present Worth Life Cycle Costing.

Year	Cost, Dollars Per Square Yard	Present Worth Factor, 4 Percent	Present Worth, Dollars
Initial Cost		1.0000	
1		0.9615	
2		0.9246	
3		0.8890	
4		0.8548	
5		0.8219	
6		0.7903	
7		0.7599	
8		0.7307	
9		0.7026	
10		0.6756	
11		0.6496	
12		0.6246	
13		0.6006	
14		0.5775	
15		0.5553	
16		0.5339	
17		0.5134	
18		0.4936	
19		0.4746	
20		0.4564	
Salvage Value		0.4564	

Total = Total =

Uniform Annual Cost = Present Worth x Capital Recovery Factor

= __________ x 0.07358

= __________

Table 17. Project Summary Sheet.

Description of Project

Location:

Type of Facility:

Critical Aircraft:

Annual Departures:

Existing Pavement:

Type of Material	Thickness	Condition	Equivalency Factor	Equivalent Thickness

Total =

Condition of Pavement

Condition Survey:

Skid Resistance:

CBR of Subgrade:

Required Thickness of New Pavement:

Equivalent Thickness of Old Pavement:

Required Overlay Thickness:

Rehabilitation Alternatives	First Cost $/yd^2	Life Cycle PW, $/yd^2	Time for Rehab.	Chance for Success

Table 18. Project Summary Sheet (Example No. 1).

Description of Project

Location: Southwestern United States

Type of Facility: Runway, length 3,200 ft. - width 75 ft.

Critical Aircraft: 24,000 lbs. gross weight

Annual Departures: 3,000

Existing Pavement:

Type of Material	Thickness	Condition	Equivalency Factor	Equivalent Thickness
AC Surface	4	Fair	1.2	4.8
Untreated Base	10	Good	1.0	10.0
Subgrade				

Total = 14.8

Condition of Pavement

Condition Survey: Alligator cracking, moderate 20 percent of area; transverse cracking, moderate, 1-4 per station; longitudinal cracks, moderate, 150 ft. per station.

Skid Resistance: Good

CBR of Subgrade: 4

Required Thickness of New Pavement: 18", min. 2" AC, 5" base

Equivalent Thickness of Old Pavement: 14.8"

Required Overlay Thickness: 3" AC

Rehabilitation Alternatives	First Cost $/yd^2	Life Cycle PW, $/yd^2	Time for Rehab.	Chance for Success
1. Asphalt-rubber chip seal to delay overlay	1.25	7.31	2 days	90
2. 3 inch AC overlay	4.95	9.88	5 days	95
3. Heater-scarification + 2 inch overlay	4.20	7.32	4 days	97
4. Asphalt-rubber interlayer + 2 inch overlay	4.55	6.76	4 days	97
5. Fabric interlayer + 2 inch overlay	4.50	7.62	4 days	97
6. Cold recycle with asphalt emulsion 6" + 2" AC	6.60	7.56	6 days	97
7. Hot recycle with AC 7"	8.10	8.46	6 days	99

Table 19. Life Cycle Costs Associated With Rehabilitation Alternatives in Illustrative Example, Dollars per Square Yard.

	Rehabilitation Alternatives							
Year	1 A-R Chip Seal	2 3" AC	3 HS + 2" AC	4 A-R + 2" AC	5 Fabric + 2" AC	6 Cold Recycle	7 Hot Recycle	8
Initial	[illegible]	4.95	4.20	4.55	4.50	6.60	8.10	
1								
2		[illegible]						
3	1.25	0.15						
4	4.95	0.20						
5		[illegible]	0.10		0.10			
6		[illegible]	0.10		0.10			
7		[illegible]	0.10		0.10			
8			0.15	0.10	0.15			
9		[illegible]	0.25	0.10	0.25			
10	[illegible]	[illegible]	2.50	0.10	[illegible]	0.05		
11	[illegible]	[illegible]		0.15				
12	[illegible]	[illegible]		0.25		0.05	[illegible]	
13	[illegible]	[illegible]		2.50				
14	[illegible]	[illegible]	[illegible]		[illegible]	0.10	[illegible]	
15			[illegible]		[illegible]	0.15		
16			[illegible]		[illegible]	0.25	[illegible]	
17		[illegible]	[illegible]	[illegible]	2.5[illegible]	2.5		
18				[illegible]			[illegible]	
19				[illegible]			[illegible]	
20				2.50			[illegible]	
[illegible]			[illegible]	[illegible]	[illegible]	1.43	[illegible]	

A-R - Asphalt-Rubber H-S - Heater-Scarification AC - Asphalt Concrete

Table 20. Calculation Form for Present Worth Life Cycling Costing - Example 1, Alternative 1.

Year	Cost, Dollars Per Square Yard		Present Worth Factor, 4 Percent	Present Worth, Dollars
Initial Cost	1.25	A-R Chip Seal	1.0000	1.25
1			0.9615	
2			0.9246	
3	0.25	Maintenance	0.8890	0.22
4	4.95	3" AC	0.8548	4.23
5			0.8219	
6			0.7903	
7			0.7599	
8			0.7307	
9			0.7026	
10	0.10	Maintenance	0.6756	0.07
11	0.10	Maintenance	0.6496	0.06
12	0.10	Maintenance	0.6246	0.06
13	0.15	Maintenance	0.6006	0.09
14	0.25	Maintenance	0.5775	0.14
15	2.50	1 1/2" AC	0.5553	1.39
16			0.5339	
17			0.5134	
18			0.4936	
19	0.10	Maintenance	0.4746	0.05
20	0.15	Maintenance	0.4564	0.07
Salvage Value	0.71		0.4564	-0.32
Total =	9.19		Total =	7.31

Uniform Annual Cost = Present Worth x Capital Recovery Factor

= 7.31 x 0.07358

= 0.538

Table 21. Representative Costs of Rehabilitation Alternatives.

Rehabilitation Alternative	Costs $/yd^2
Asphalt Cement Chip Seal	0.86
Asphalt-Rubber Chip Seal or Interlayer	1.25
Fabric Interlayer	1.20
Heater-Scarification	0.90
Asphalt Concrete - One Inch	1.65
Asphalt-Rubber Interlayer With 1.5 Inches Asphalt Concrete	3.73
Fabric Interlayer With 1.5 Inches Asphalt Concrete	3.68
Heater-Scarification With 1.5 Inches Asphalt Concrete	2.23
Cold Recycle 6 Inches + 2 Inches Asphalt Concrete	6.60
Hot Recycle 7 Inches	8.10

Table 22. Project Summary Sheet (Example No. 2).

Description of Project

Location: Southeastern United States

Type of Facility: Taxiway - 6,000 ft. x 100 ft.

Critical Aircraft: Dual wheel gear, 200,000 lbs. gross weight

Annual Departures: 6,000

Existing Pavement:

Type of Material	Thickness	Condition	Equivalency Factor	Equivalent Thickness
AC Surface	4	Poor	1.0	4.0
Untreated Base	14	Good	1.0	14.0
Untreated Subgrade	18	Good	1.0	18.0

Total = 36.0

Condition of Pavement

Condition Survey: Center 30 ft. badly alligator cracked on over 50 percent of the area. Areas outside center 30 ft. are in good condition.

Skid Resistance: Good

CBR of Subgrade: 5

Required Thickness of New Pavement: 43", min. 4" AC, 14" base

Equivalent Thickness of Old Pavement: 36.0

Required Overlay Thickness: 7"

Rehabilitation Alternatives	First Cost $/yd^2	Life Cycle PW, $/yd^2	Time for Rehab.	Chance for Success

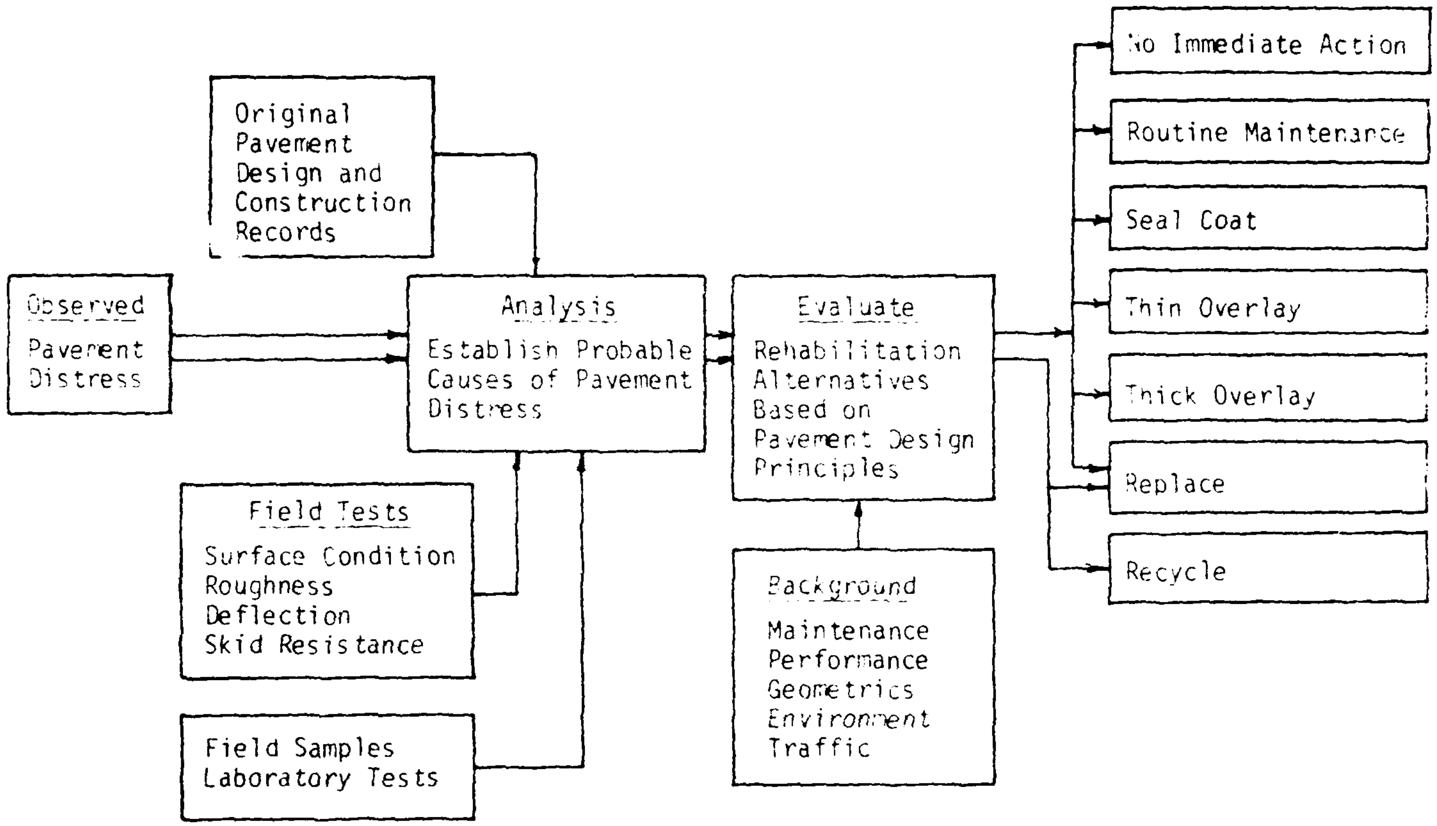

Figure 1. Selection of a Rehabilitation Alternative. (After Reference 23)

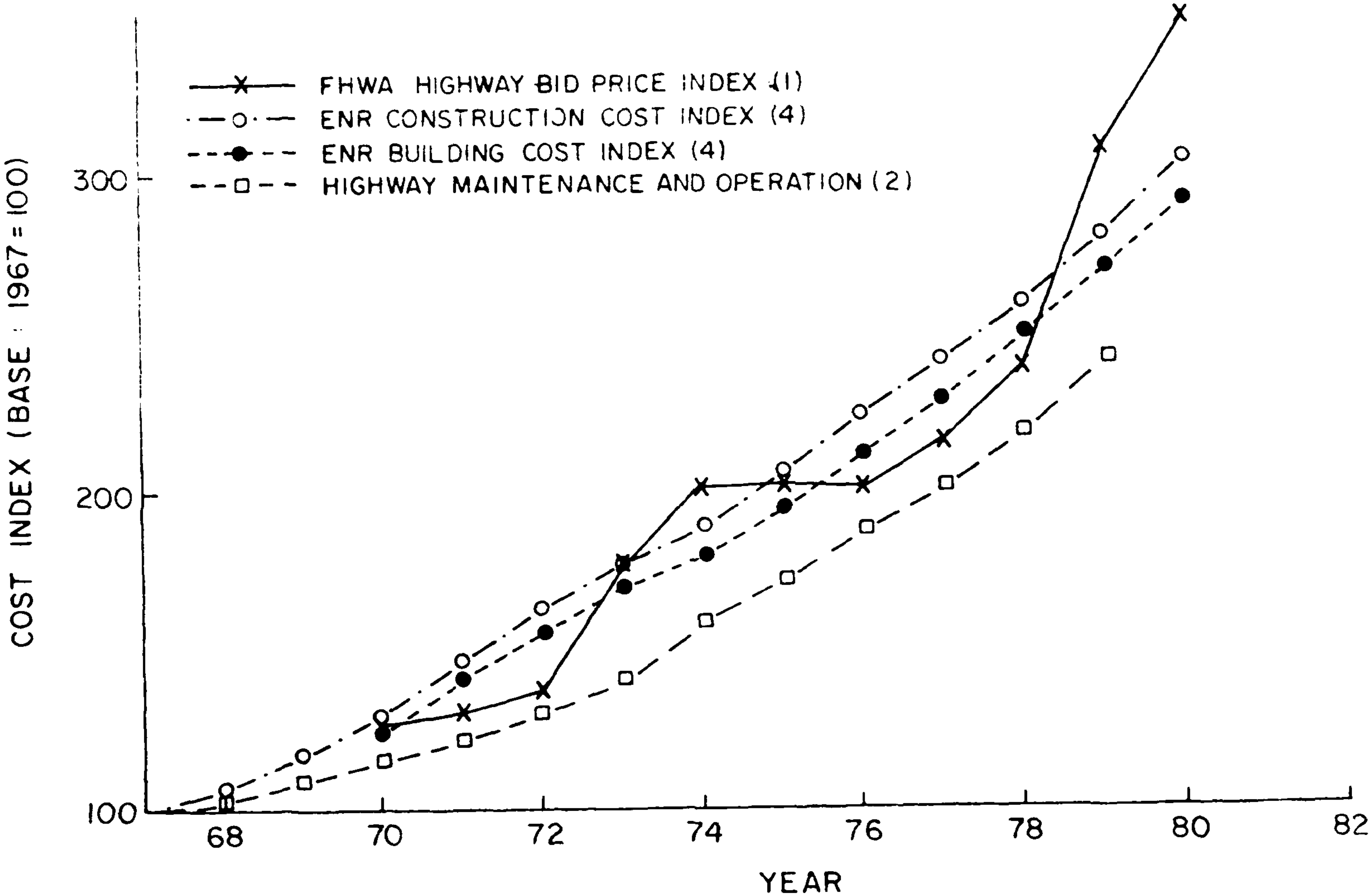

Figure 2. General Construction Cost Indexes.

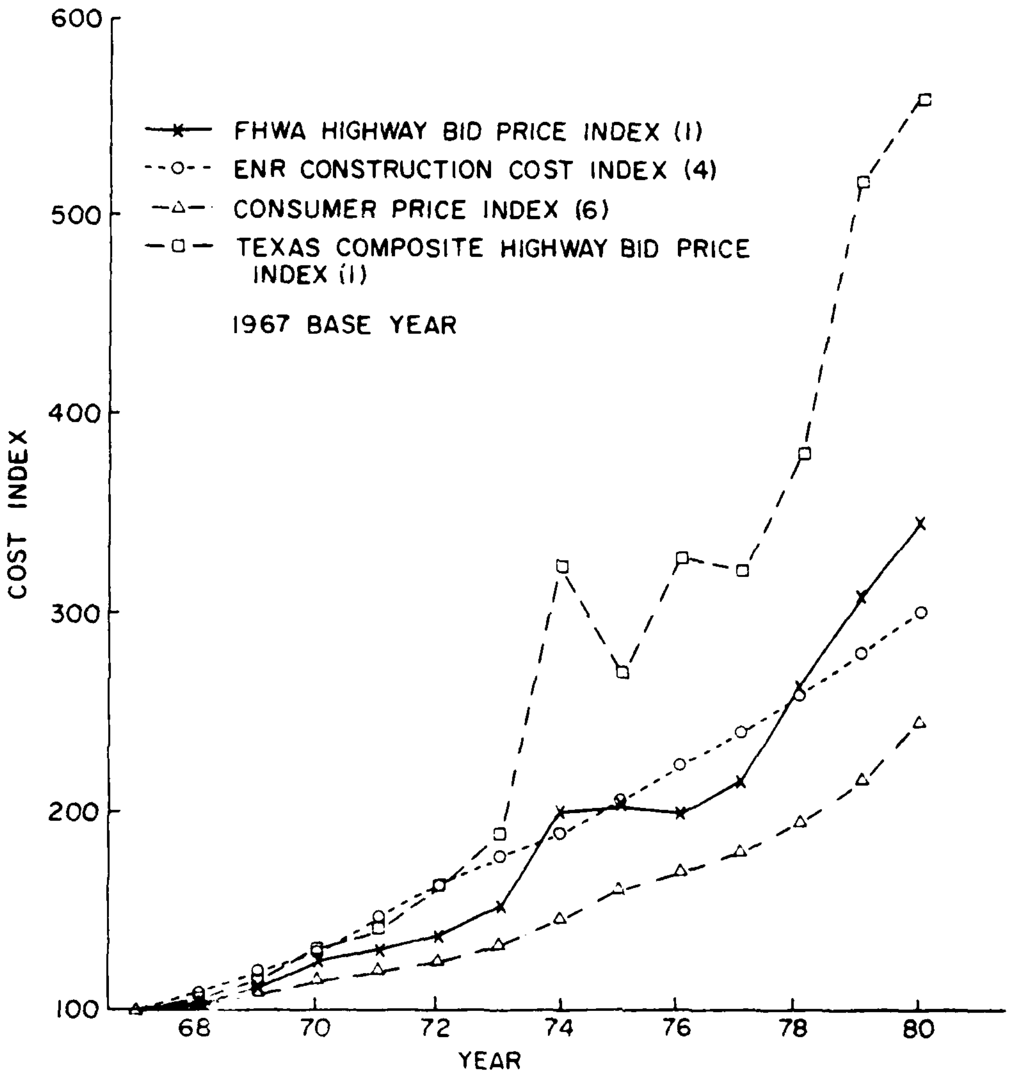

Figure 3. A Comparison Among Construction Cost Indexes and Consumer Price Index.

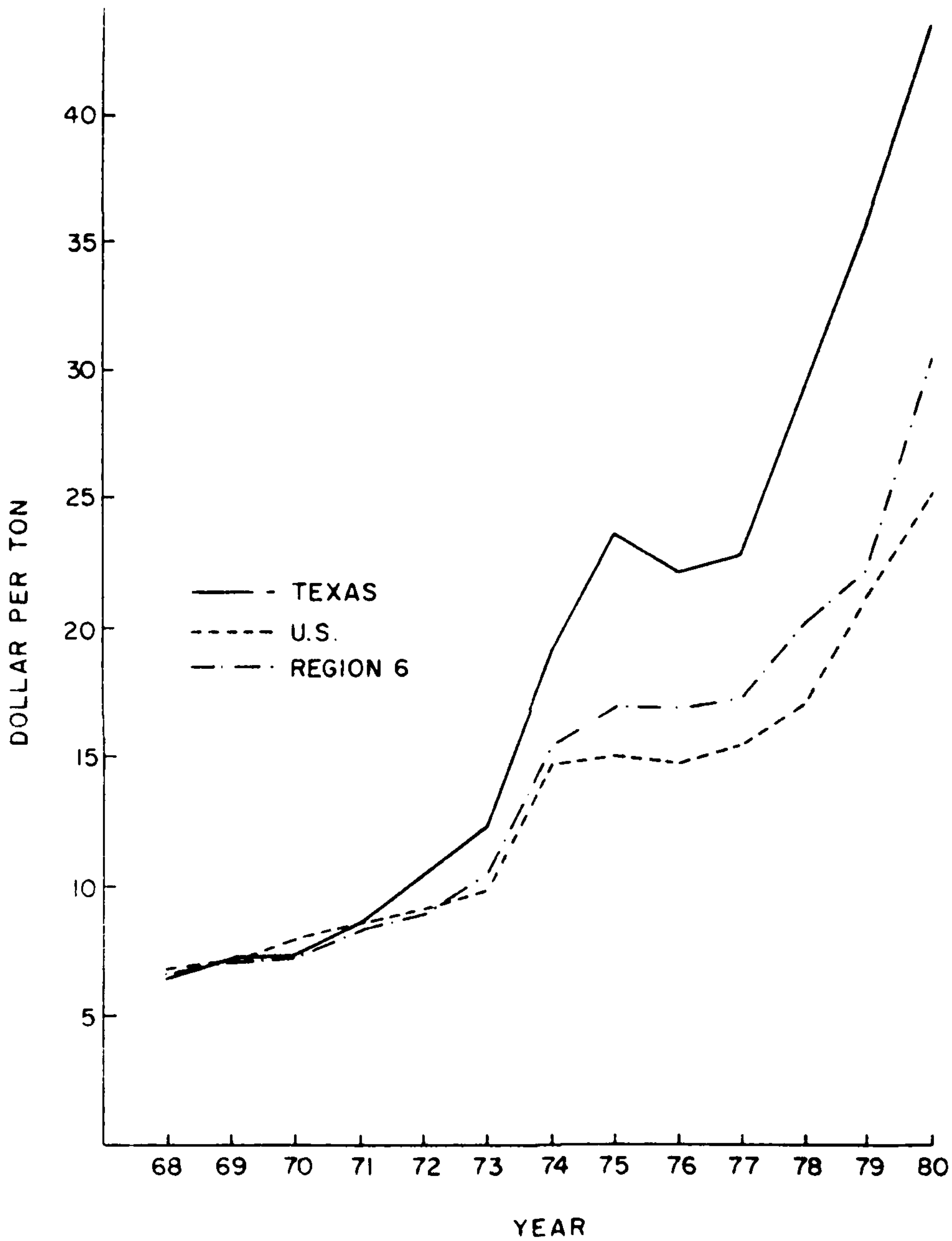

Figure 4. Average Annual Contract Price for Bituminous Concrete. (After Reference 57)

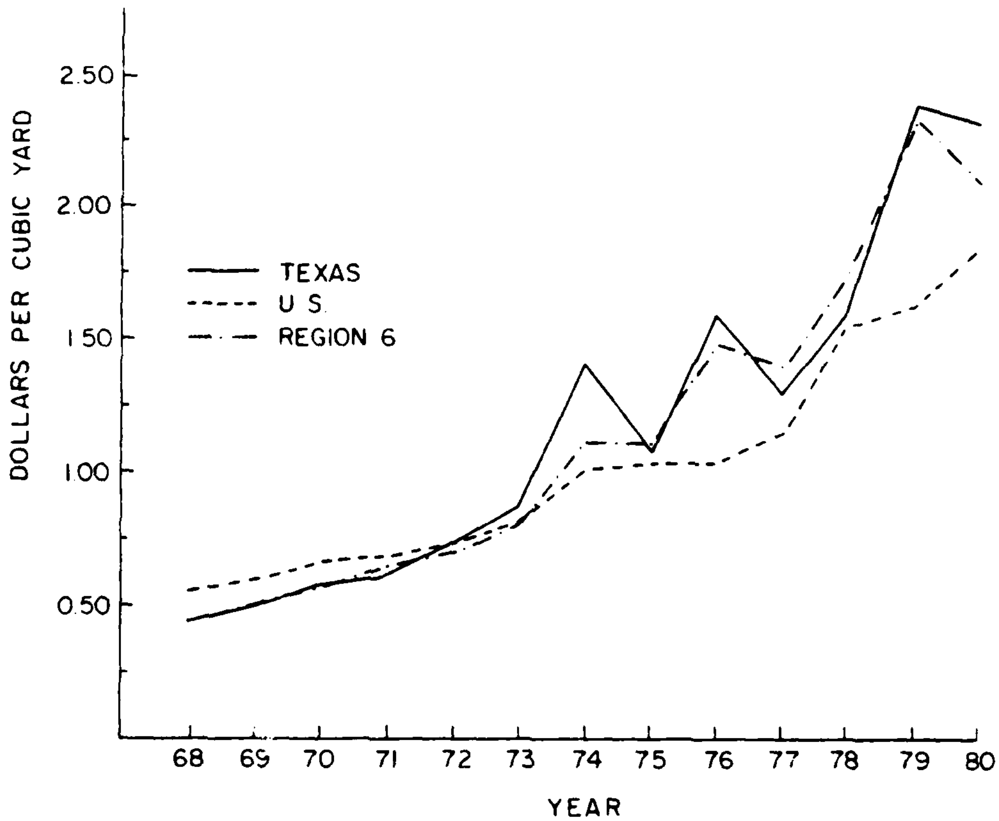

Figure 5. Average Annual Contract Price for Common Excavation.
(After Reference 57)

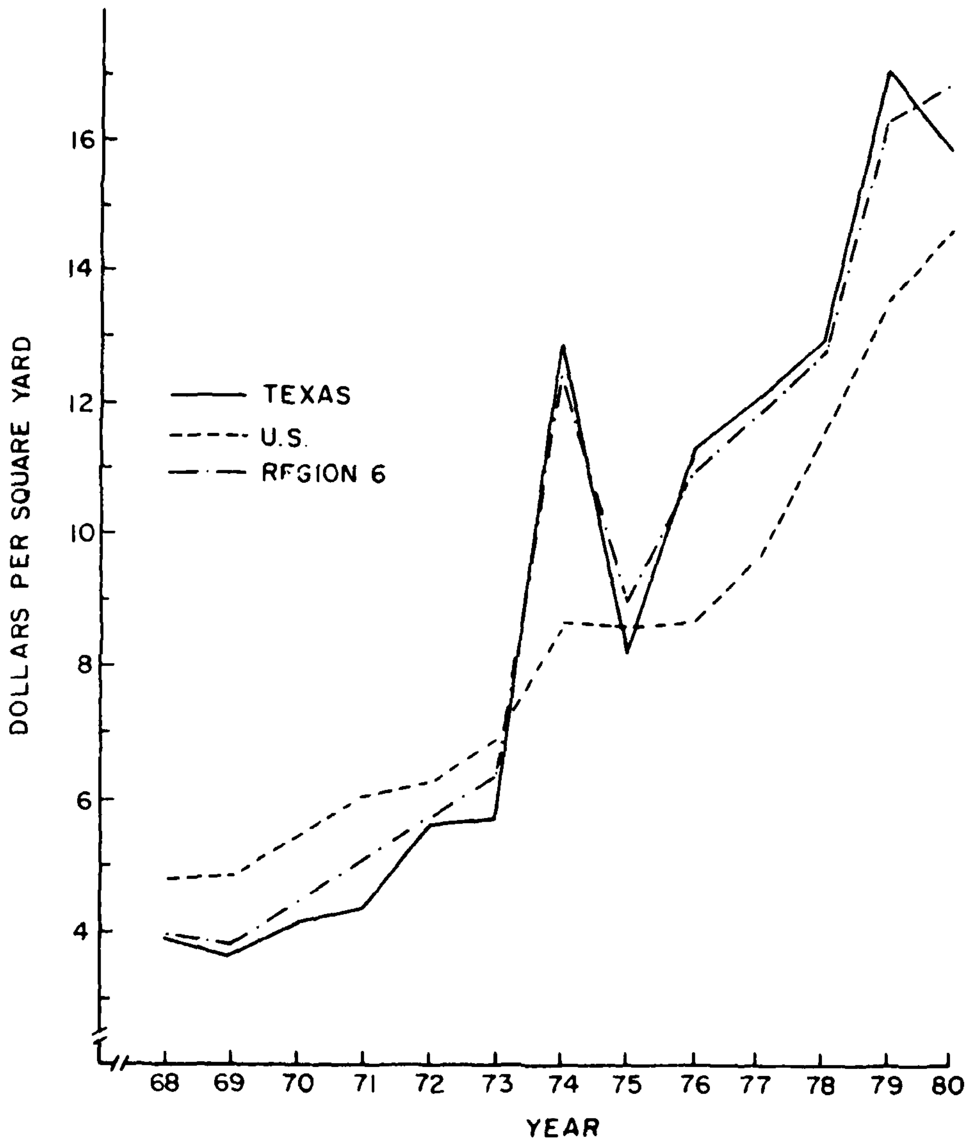

Figure 6. Average Annual Contract Price for Portland Cement Concrete Pavement. (After Reference 57)

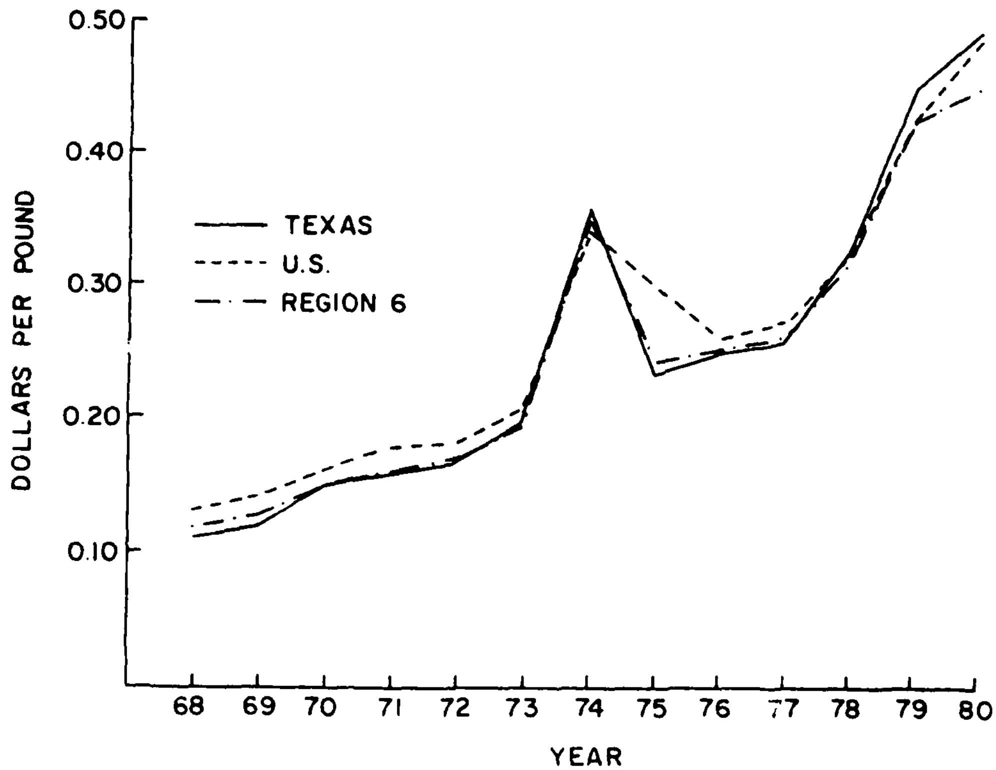

Figure 7. Average Annual Contract Price for Reinforcing Steel. (After Reference 57)

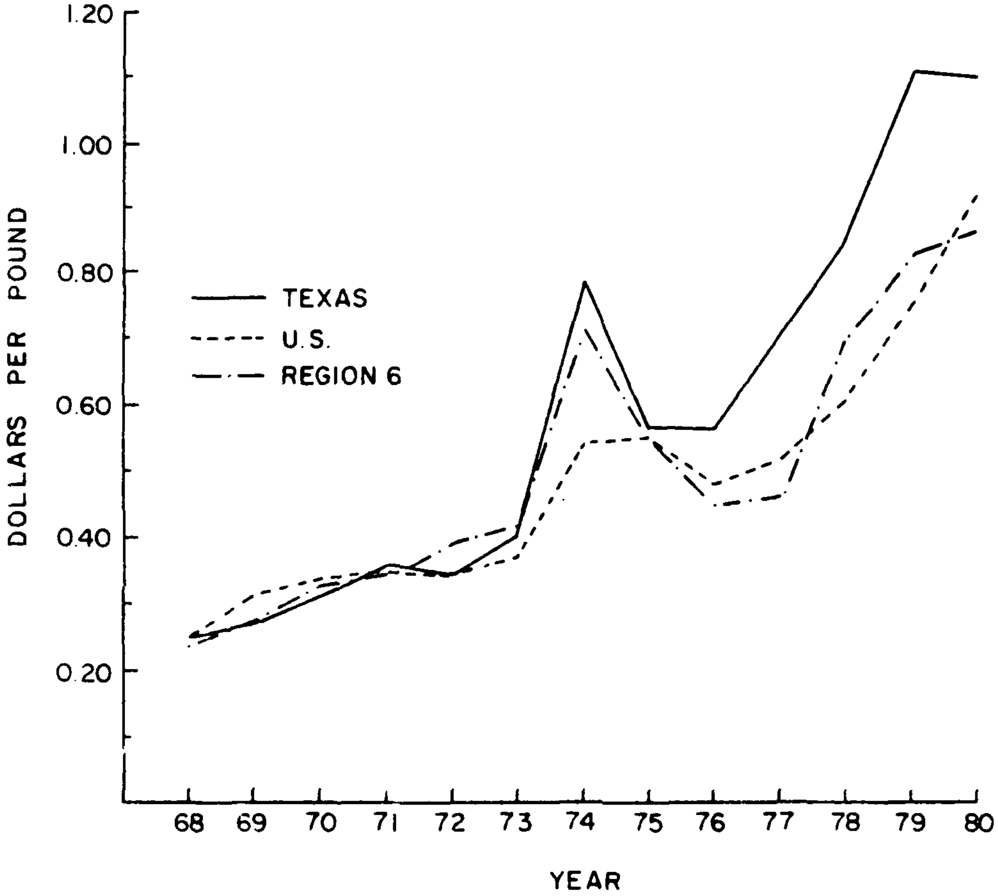

Figure 8. Average Annual Contract Price for Structural Steel. (After Reference 57)

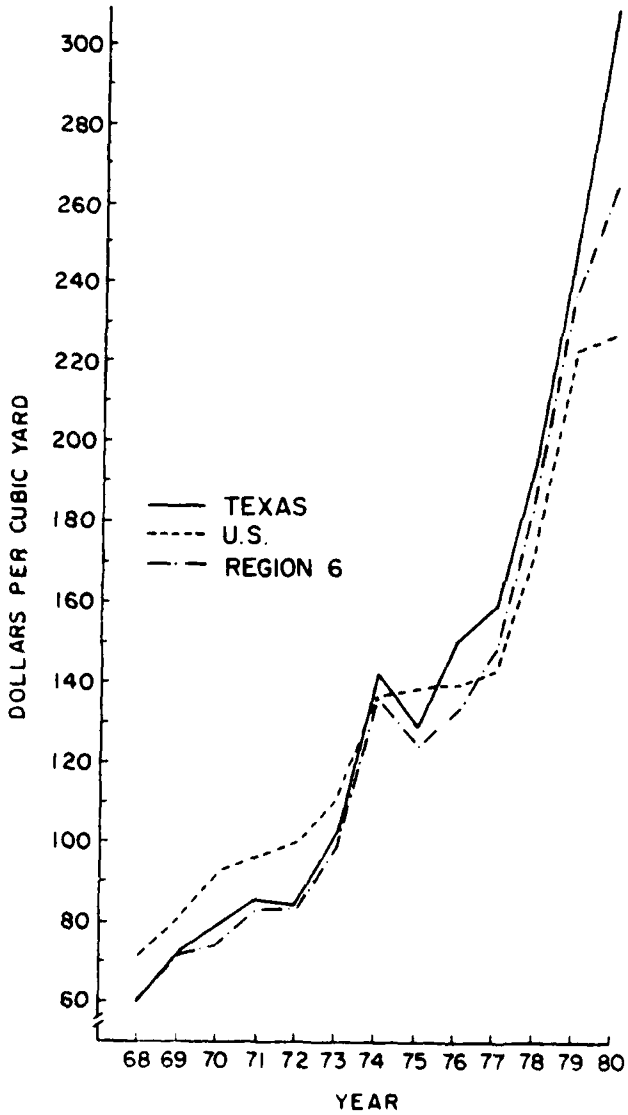

Figure 9. Average Annual Contract Price for Structural Concrete. (After Reference 57)

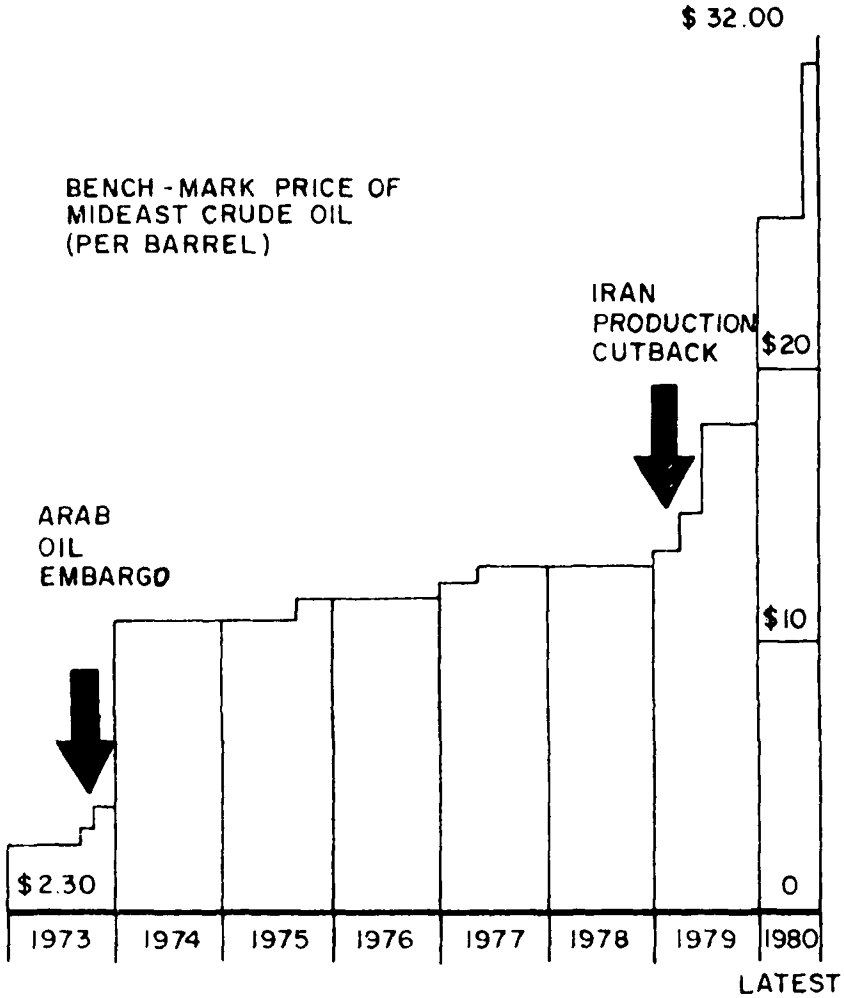

Figure 10. Imported Mid-East Crude Oil Price Trends 1973 to 1980. (After Reference 60)

Note: Price excludes shipping cost to U.S.

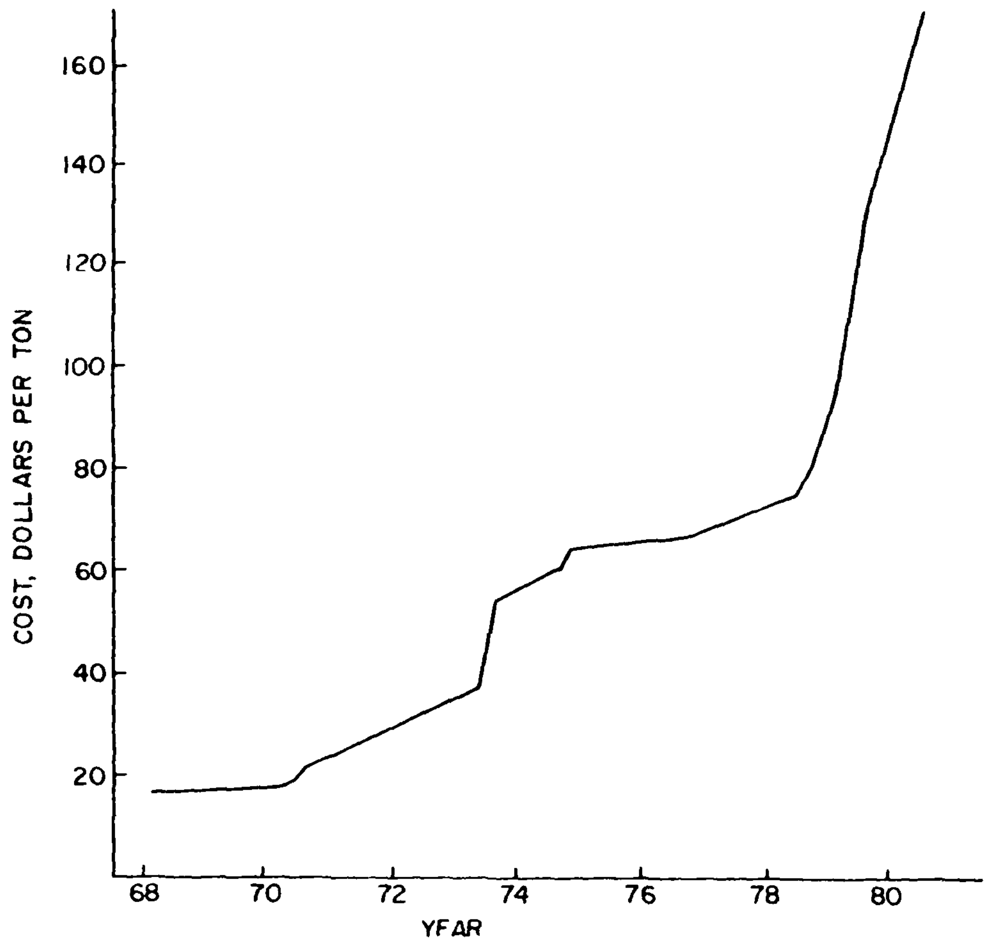

Figure 11. Posted Price of AC-10/20 Asphalt Cement - Texas. (After Reference 61)

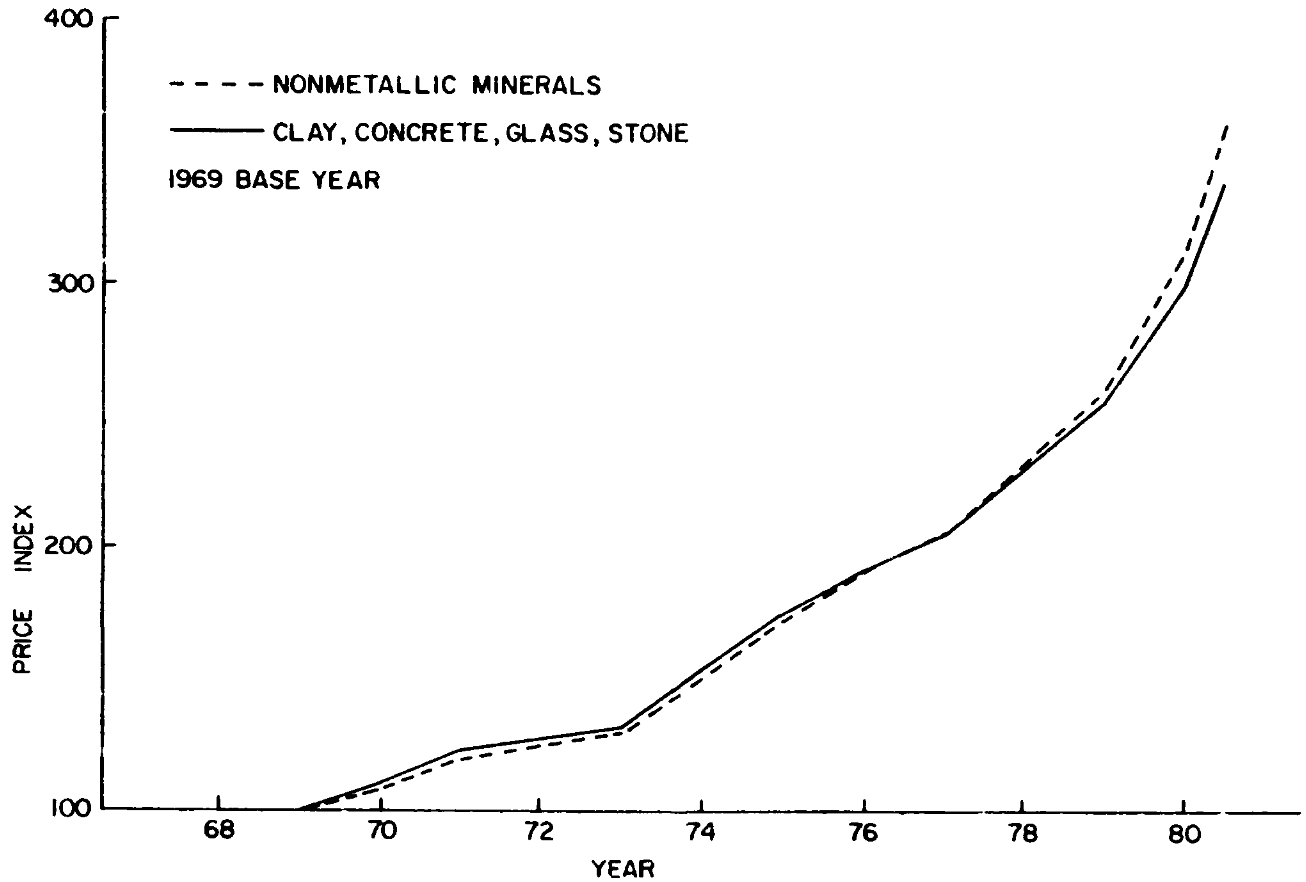

Figure 12. United States Price Index for Railroad Freight.
(After Reference 62)

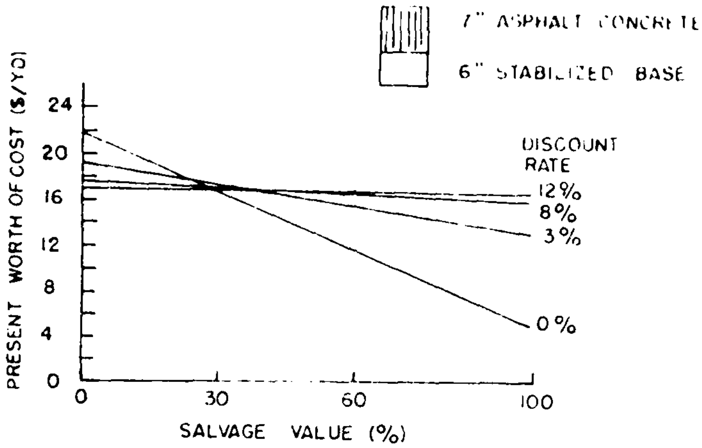

Figure 13. Influence of Selected Discount Rate and Salvage Value on Present Worth of a Typical Flexible Pavement. (After Reference 12)

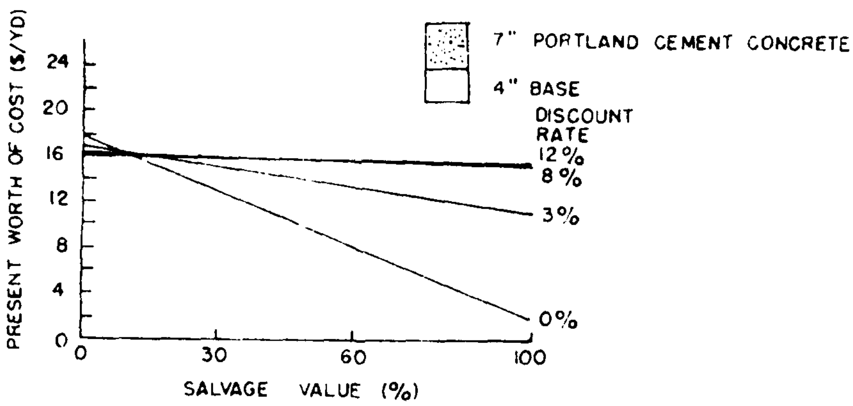

Figure 14. Influence of Selected Discount Rate and Salvage Value on Present Worth of a Typical Rigid Pavement. (After Reference 12)

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